DETERMINING ENERGY REQUIREMENT FOR FUTURE WATER SUPPLY AND DEMAND ALTERNATIVES

by

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ABSTRACT

Water and energy are two inextricably linked resources. Each has the potential to limit the development of the other. There is a substantial body of research dedicated to understanding how the availability of water can limit energy production, but the alternate relationship – that of energy limiting water production – has received much less scrutiny. The demand for both resources is predicted to increase in tandem with population growth, potentially creating or adding to conflict in regions of water or energy scarcity.

To greater understand the "water/energy nexus," – a commonly used term to describe their interdependence – each phase of water supply and consumption can be broken into discrete segments that have an associated energy requirement, called an energy factor. An energy factor is the amount of energy used to develop, convey and treat a given volume of water. This study presents a methodology for calculating the energy factors of each phase of the water supply cycle that is "outside the retail meter." A case study of a large water system in an arid region of the United States is used as an example system for applying these methods. Using the case study system as a framework, an energy demand model is developed that estimates baseline energy usage for heterogeneous water systems, and then models changes in energy requirement under three alternate water supply and demand scenarios. The results of the model scenarios reveal that water demand reductions, as can be brought about by targeted water efficiency programs, can have extended energy-saving impacts – affecting all other phases of the water supply cycle. A demand reduction of 25% for the case study water system resulted in a cumulative annual energy savings of 8.9 million kilowatt hours (kWh) – a decrease of 28% from its current level of energy consumption. Modeling the conversion of agricultural or currently untreated water to municipal uses within the case study resulted in an increase in energy requirement by 6.3 million kWh – a 20% increase. Reductions in the availability of imported surface water supply, such as those brought about by prolonged drought, climate change or reservoir sedimentation, can increase energy demand as well. An additional 5.7 million kWh are needed to ameliorate the effects of a 35% reduction in surface water supply for the case study water system – an 18% increase from its current energy requirement. The process and findings of this study reveal a lack of emphasis among water agencies concerning energy consumption, and indicate that changes in supply and use patterns have dramatic effects on energy usage.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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CHAPTER 1

INTRODUCTION

Population in the United States is projected to grow to 364 million by 2030 and 420 million by 2050 (U.S. Census Bureau). During the same time frame, energy use is projected to grow at an annual rate of 1.3%, requiring an estimated additional 1,328 billion kilowatt hours (kWh) of electricity and water demand is projected to grow in tandem (DOE/EIA 2008). As population grows, so does the demand for energy and water. Meeting demand for both of these critical resources poses a challenge to energy utilities and water managers alike, on a global and local scale. The lack (or shortage) of water can limit the production of energy. All methods of energy extraction or generation, whether from coal, oil shale, nuclear, geothermal, solar power, etc., come with a requisite demand for water (Sovacool, 2009, DOE 2006, Bauer 2009). These demands have already become a limiting factor in energy development, such that many plans for new power-plants have experienced delays or been shelved indefinitely (DOE/NETL 2008). The alternate relationship – that of the availability of energy limiting the availability of water – is also constrained. Providing water where it is needed, whether near or far, for agriculture or culinary use, can be a highly energy-intensive process and extremely contentious (Zimmerman 2008).

In an effort to facilitate the study of the water supply and consumption processes, a conceptual diagram of water collection, conveyance, distribution, treatment, end-use, wastewater treatment, recycling and discharge back to the natural system is presented in Figure 1. Each phase in the diagram has existing or emerging energy-related issues that have often not been of primary importance when considering possible water supply, conveyance and treatment options. The need to develop new water supply sources and the associated capital investment costs can obscure or down-play the long-term energy costs involved in operation and maintenance.

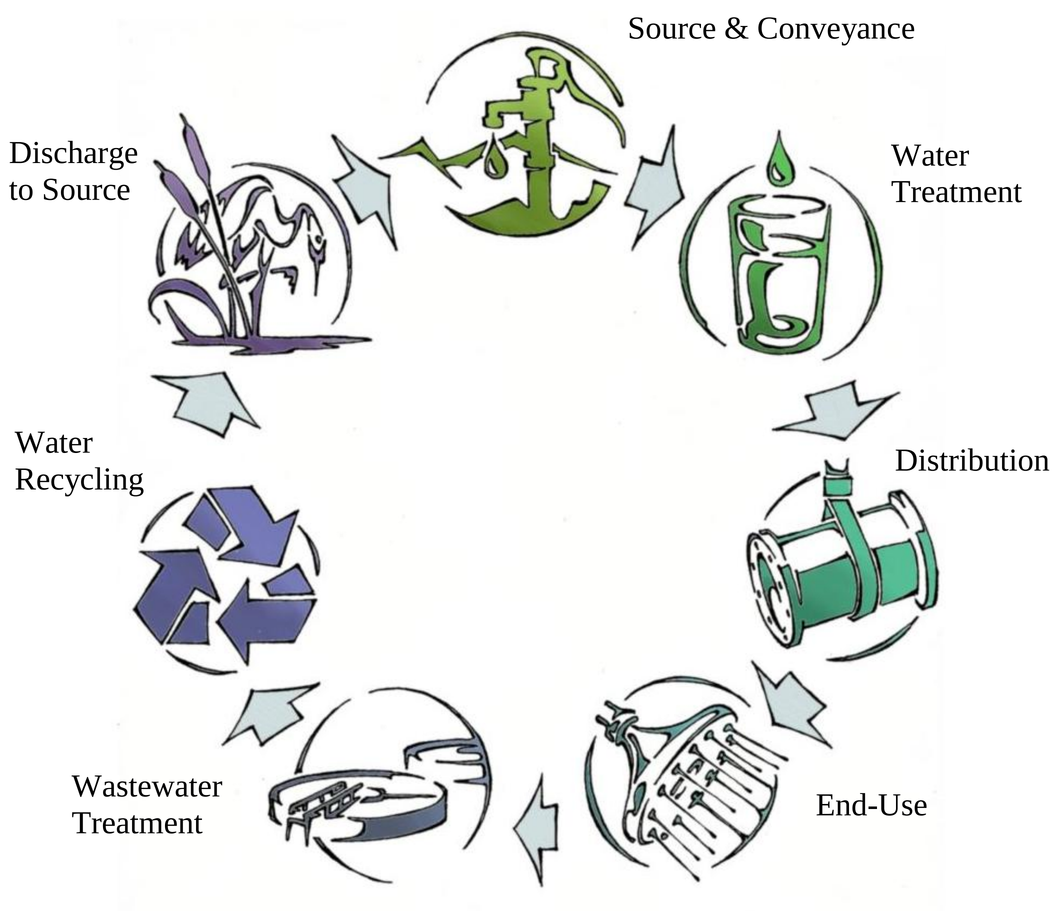

Figure 1. Water supply and consumption cycle diagram

Also, water agencies frequently purchase energy at an industrial rate that may be much lower than that paid by a typical residential or retail customer, making energy-intensive projects more likely than they would be otherwise. An example of neglecting energy within the "Source" phase of the cycle has occurred in southern California. State regulators approved the installation of one of the world's largest desalination plants near San Diego. Currently, desalination is one of the most energy-intensive and financially costly means of supplying water. The new facility will require about 274,400 Megawatt hours (MWh) of electricity each year, to produce 50 million gallons per day (MGD) of drinking water. For comparison, importation via California's State Water Project (SWP) – over 444 miles and 3,000 feet over the Tehachapi mountain range – requires about 134,000 MWh for the same volume of water (Wilkinson 2000, California Energy Commission 2005, California Department of Water Resources 2009). A study conducted by Stokes et al. (2009) further quantified this gap in energy expenditures and extrapolated them into the future. First, they estimated that the energy and greenhouse gas (GHG) footprint of seawater desalination is 1.5 – 2.4 times larger than that of imported water in California, similar to the figures estimated above. They also estimated that meeting the annual water needs of a typical Californian (about 11,700 cubic feet) with desalinated water would require 3,889 kWh of energy and emit 1,760 pounds (lbs) of carbon dioxide (CO_2) annually, compared to 1,612 kWh and 790 lbs of CO_2 using imported water. Second, they analyzed the energy and GHG impacts of meeting the state's additional water demand in 2030 using a variety of sources, including water importation, water recycling and three desalination treatment methods. They found that meeting future demand with the most energy-intensive method, that of desalinated ocean water with conventional pretreatment, would consume 52% of California's total energy budget at that time. Although desalination is growing quickly as a water supply source – on the order of 10% growth each year – it is only one available option when considering alternative water supplies (Hightower 2007). In contrast to desalination, using recycled water (reclaimed wastewater) to meet demand in 2030 would require only 21% of California's total energy budget (Stokes 2009). Recycled water, although not of drinking water quality and requiring separate distribution systems, has been found to be functionally equivalent for landscape irrigation and other applications, and can be one of the least energy intensive sources of water available (California Energy Commission 2006). It has the potential to significantly offset culinary water use, but is less likely to be considered an option because it is perceived as a lower quality product, has a high initial cost of implementation and may require additional pumping to return it to the point of use. Nevertheless, water recycling is forecast to grow at an appreciable 15% every three to four years (Hightower 2008). The difference in energy consumption between the two water supply options reinforces the need for water suppliers to consider the long-term energy impacts or life-cycle costs when assessing water supply options and proposed projects.

Another example of the lack of energy awareness when looking at water supply options is the increasing reliance on groundwater. With the advent of hydraulic pumping, groundwater supplies became available for withdrawal on a much greater scale than they were historically. When groundwater is withdrawn faster than the natural system can replenish, the water level drops and even greater amounts of energy are required to pump water to the surface. The added financial cost is usually negligible (because it occurs gradually) and in this way inexpensive fossil fuels enable often unregulated pumping of "fossil" groundwater aquifers. Groundwater overdraft is widespread around the globe, from the U.S. to India, from Mexico to the Middle East. Many of these countries or regions have been withdrawing water from historic aquifers at accelerated rates, such that their withdrawals far exceed the rate of aquifer recharge (Gleick 1994, Shah 2009). Periods of greater groundwater demand commensurate with dry years and prolonged drought can exacerbate this condition. During such periods, groundwater sources may be used to compensate for a reduction in surface water storage (California Energy Commission 2005). This, combined with existing overdraft practices, creates a "lose-lose" situation wherein the resource is depleted and the energy to retrieve it also rises prohibitively. Despite attempts to institute legal and regulatory oversight over groundwater mining, there is little incentive to correct the practice until issues surrounding subsidized or inexpensive fossil fuels are addressed as well (Scott 2004). How much water will be available to meet future demand from groundwater sources, and how much energy its retrieval will require, is unknown.

After a water source has been developed it must oftentimes be conveyed, sometimes over long distances and high elevations, to its destination. In some locations water suppliers can take advantage of gravity to move water from higher elevations to its place of use, perhaps generating hydropower and pressurizing distribution networks at the same time. However, in many regions these "easy" sources of water have already been fully developed. Future supplies will require developing sources that are farther away and require additional energy to deliver. Many long-distance water transfers are currently being considered or implemented that involve pumping water over great distances or elevations (Tellinghuisen 2009). An example of how energy-intensive water conveyance can be is the California Aqueduct, a pipeline that conveys water across two mountain ranges to southern California. The combined pumps and booster stations on this system constitute the largest energy consumer in the state (Webber 2008).

Great geographic and temporal disparities can exist between locations with high precipitation and the urban centers where water is ultimately delivered. China faces this common problem, with plentiful precipitation in the southern regions and an arid north. In an effort to resolve this disparity, massive water projects are under construction. These include the South-to-North Water Transfer Project, the largest water transfer of its kind ever undertaken (Cheng 2009). After its completion in 2050, China's four largest rivers will be interconnected and will convey almost 36.3 million acre-feet (ac-ft) over a total distance of about 2,300 miles. The lifts required for this conveyance are small, (requiring only 30 pump stations with a capacity of 453.7 MWh), but the design plans call for miles of tunnels bored through mountain ranges to avoid pumping (Changjiang Water Resources Commission 2009, Watertechnology.net 2009). The energy related to simply construct such a project is very large. In general, around the world, solving the spatio-temporal disparity of water supply and consumption will require longer transfers and greater lifts, with a requisite energy demand that is unknown.

Water treatment is the third phase within the water supply and consumption cycle. Only a portion of the water of a particular source may be treated to culinary drinking water standards. Water used for agricultural purposes or within a secondary system (untreated water designated for residential and commercial landscape irrigation) has no water treatment energy costs. However, many water suppliers suggest that some of their future water supply will be found by converting agricultural water to municipal and industrial uses (Utah Division of Water Resources 2004). The additional energetic cost of treating agricultural/secondary water is usually low, but can become expensive if the water is heavily contaminated, brackish or saline. For most water treatment systems the primary energy costs are related to the amount of water that must be pumped at the facility, and to the life-cycle energy costs of chemicals used in the treatment process (NRDC 2004). In this manner, the volume of water treated directly impacts the required energy.

Another concern for water treatment plant operators is that of new and more stringent water quality standards. Energy costs for water treatment rose in the mid-1990s in response to new environmental regulations as mandated in the Clean Water Act (CWA) (Neukruq 1995). These regulations placed new restrictions on pollutants that were previously unregulated and also required reductions in disinfection byproducts. To meet those new standards and for safety reasons, more water suppliers explored alternative water treatment technologies such as ozonation and ultraviolet light disinfection. These methods of treatment are more energy intensive than traditional flocculation, settling and chlorination disinfection processes (Douglas 1993).

One of the greatest energy expenditures in the water supply and consumption cycle is wastewater treatment. Facilities are meeting current discharge water quality standards, but there is growing evidence that the nutrient loads in wastewater are damaging to the environment. Wastewater treatment facility managers are concerned about more aggressive nutrient removal regulations, possibly necessitating additional infrastructure and energy costs. It has been estimated that advanced wastewater treatment with additional nitrogen removal can triple energy costs compared to simpler treatment methods like trickling filtration (EPRI 2002). Alternate disinfection methods of treatment such as ozonation and ultraviolet light disinfection are more energy-intensive than more traditional chlorination. Endocrine disrupting compounds (EDCs) and other micro-pollutants are of concern for human and ecosystem health, would likely increase required treatment energy substantially and are under review for inclusion in water quality standards (Ternes 2007). Pilot projects exploring EDC removal, such as granular activated carbon, ozone, membrane filtration and reverse osmosis, are underway in the U.S., the European Union (E.U.) and the United Kingdom (U.K.) (Burke 2004, Clara 2005, Benotti 2009). These methods of water purification are used for culinary water treatment already, but may be environmentally and fiscally undesirable for large-scale wastewater application due to their high energy costs and related GHG emissions (Jones 2007). More aggressive contaminant removal is presumed to benefit the aquatic systems within the receiving body of water and the environment as a whole, but a corresponding higher energy demand and greater GHG emissions should be considered as well. The prevailing consensus among wastewater industry professionals is not if more regulation will be enacted, but simply a matter of when and how much. Whatever additional water quality regulations are put in place will likely affect the industry in a broad fashion and require more infrastructure and energy. The energy impacts of treating water to more stringent standards, especially with the possible inclusion of micro-pollutant removal, are not well understood.

The end-use segment is the largest consumer of energy within the water supply and consumption cycle, and constitutes over half of the total system energy demand in places like California (California Energy Commission 2006). This reflects the large amount of energy that is required to heat, cool and pump water within residential, commercial and industrial facilities. As a consequence, efficiency programs targeted toward end-use have the greatest potential to reduce water-related energy consumption and can be greater than actions directed toward water supply and treatment. Prioritizing water efficiency funding, offering incentives, implementing effective pricing structures and enforcing water efficiency ordinances can have significant environmental and economic impacts. This stage is also considered to be "within the retail meter" and is therefore under the purview of water agencies themselves, usually with program assistance from governmental agencies. This study focuses on the energy costs associated with "outside the retail meter" phases of the water supply and consumption cycle, which are highly variable and more difficult to assess.

1.1 Literature on Energy for Water

There are many studies addressing energy requirements for water-related services at both large and small scales. The Electric Power Research Institute (EPRI) began releasing broad-based, national studies in the late 1990s that address energy consumption by water-related services and by end-use categories (EPRI 1999b, EPRI 2002). Their report issued in 2002, *Water & Sustainability (Volume 4)*, quantified energy required per volume of water (kilowatt hours per million gallons) and then applied these figures to estimate total energy usage by selected sectors of the economy. EPRI has since updated its 2002 evaluation to include a thorough analysis of water technologies with energy efficiency potential such as high-efficiency pumping, pipeline optimization, end-use efficiency measures, advanced treatment methods and desalination (EPRI 2009).

Another broad-based study was conducted by the California Energy Commission (CEC) in 2005. They found that 19% of the state's electrical energy use and 30% of their natural gas consumption was dedicated to water-related services, including end-user heating and cooling (California Energy Commission 2005). The same approach to quantifying energy usage – that of energy use per volume of water – was also used, and illustrated the high energetic cost of water particularly within the "Source and Conveyance" category, reflecting the long distances and lifts of California's water importation. This study was later updated with the inclusion of better substantiated data and more refined estimates for each per-unit energy demand for each phase of the water supply and consumption cycle (California Energy Commission 2006). These energy intensity estimates also took "water system losses" into account. This is an estimate of the amount of water lost as it flows from source to end-user due to leaking, evaporation, seepage or maintenance processes. Another important inclusion in the CEC 2006 update is a breakdown of the energy requirements within each cycle and also by geographic area (Northern and Southern California) an acknowledgement that geography-related characteristics (elevation change, water quality, groundwater table, etc.) plays an important role when estimating energy demand for local or regional water.

In 2004 the National Resources Defense Council and Pacific Institute released a report that addressed each phase of the water supply and consumption cycle, and extended estimated energy quantities further, by calculating the resulting GHG emissions under a variety of energy-mix regimes. These ranged from the current California mix, to wider use of "renewables," to strictly thermoelectric energy use. They also released a tool that would assist water managers by estimating their energy demand by sector and the resulting GHG emissions from energy mix scenarios (NRDC 2004). This extrapolation to GHG impacts was used again by water planners in Fairfax, Virginia. They developed a Geographic Information System (GIS) based tool that used the spatial extent of a water system and other parameters to estimate energy consumption and GHG emissions (Bahkshi 2009).

Life-cycle assessment (LCA) has become an important tool for quantifying and minimizing the environmental aspects of a product, process or service. LCA addresses all phases of development, from material extraction and construction, through a period of use and eventual disposal or reuse. For example, a typical LCA for water-related services attempts to quantify the expenditures of fabrication, use and end-of-life stages of a water source conveyance, a pipe network, a treatment plant or even new treatment methods or processes. Stokes et al. (2009) provided a comprehensive LCA of different water supply options for California. Their results also included GHG impacts using a variety of energy mixes and a comparison of desalination in California to other regions that are heavily reliant on the same technologies for their water supply. LCA research conducted by Filion et al. (2004) quantified the energy costs of a water distribution system. They modeled pipe fabrication, installation costs and pipeline breaks over the lifetime of a distribution system. They concluded that, for the kind of distribution networks in their modeling and analysis, a pipeline replacement timeline of 50 years was optimal. There are many LCA studies dedicated to wastewater processes and new treatment technologies. Tangsubkul et al. (2005) evaluated different treatment methods of recycling water to nonpotable standards for energy and environmental impacts. Similarly, a LCA by Das et al. (2002) compared the use of ultraviolet light disinfection to more traditional chlorination and de-chlorination methods. They presented evidence to support the theory that, despite the increase in energy consumption, the newer treatment technologies were environmentally beneficial in the long-run. Racoviceanu et al. (2007) performed an LCA on initial water treatment chemical production, transport and plant operation, finding that plant operational components accounted for most of its energy usage. They also found that pumping of effluent throughout the plant was usually the primary energy consumer. Arpke et al. (2006) examined the water supply and consumption cycle phase with the highest energy requirement, that of indoor end-use, by performing LCA on water usage within four building types. They found that, of the four types – apartment complex, college dormitory, motel and office building – apartment buildings have the highest energy usage per unit volume of water, and office buildings have the most energy efficient water use.

Studies on energy optimization of water treatment or the individual components of water supply are prevalent in the literature. Some focus on optimal energy mixes and operations for water given a locale with specific physiographic characteristics, such as in Ramos et al. (2009) and Vieira et al. (2008). Components of a water distribution or treatment system can often increase their energy efficiency by optimizing their operation, as is suggested by Bunn et al. (2009), or by using a Supervisory Control and Data Acquisition (SCADA) system, as suggested by EPRI (1998, 1999a). Suggestions for removal of pressure reduction valves in favor of small hydropower energy generation, also called micro-turbines, are beginning to be investigated as a means of offsetting water system energy costs (Ramos 2007, Smith 2008). Wastewater processes have significant potential for energy generation, and it has even been suggested that biogas and methane production serve as source of revenue in the form of carbon credit and emission trading (Show 2008).

Finally, many studies suggest that the greatest energy efficiency gains to be made in many locations are found with reductions in water demand itself. Using a case study site in Melbourne, Australia, Flower et al. (2007) found that with a combination of structural and non-structural demand management strategies, individual household water consumption could be reduced by 65% and GHG emissions by 63%. The savings had a cascading effect from the end-user phase throughout the entire water supply and consumption cycle. They proposed that, with carefully targeted demand reducing programs, the environmental and economic benefits would not only be seen by consumers, but by water agencies that would be able to delay costly water development and treatment. The California Energy Commission also stated that it was possible to meet 95% of their energy efficiency goals indirectly through less expensive water efficiency programs, emphasizing the gains to be made in the end-use sector for that region (California Energy Commission 2005, Alliance for Water Efficiency 2008).

In summary, the body of knowledge concerning the “water/energy nexus” is growing rapidly. Much progress has been made toward substantiating viable solutions to problems created by this growing issue. However, on a local and regional scale, every water system is unique and has its own configuration of water sources, conveyance, distribution and treatment. Large-scale studies provide an overview of common issues, but are generally too coarse to apply to the majority of small and moderately-sized water systems. Conversely, LCA studies look to define the lifetime energy costs of a system in extreme detail. Information is available for water suppliers at these two scales and for individual components, but studies addressing the needs of more common water systems – those that are comprehensive but detailed enough to include key system components - are lacking. As a consequence, water suppliers are often at a loss to assess their current energy requirements and to extrapolate these energy requirements into the future. They need a methodology for discovering their current energy requirements. They also need to be able to adapt their system management to sometimes abrupt changes like decreasing water supply, water demand or new regulations. For example, a decrease in demand from end-users, such as provided by a successful water efficiency program, has the potential to decrease energy requirement significantly but not always in an obvious or linear fashion. The opposite is true for urban growth and increased water demand. Energy requirements could also change with alteration in usage patterns. As mentioned earlier, many municipalities are expecting to meet some of their future demand with conversions in water application, such as a conversion from agricultural irrigation to municipal and industrial uses. In such cases, the source of water is often already developed and a distribution network in place. However, agricultural water is untreated and converting it for purposes that require higher water quality would require added energy for each phase in the "downstream" cycle. Surface water sources are the least energy intensive water for many communities, but these are also subject to drought and shortages. Even more significant reductions in precipitation and surface storage are implied by recent studies and literature surrounding climate change.

The objectives of this study are to develop an analysis framework to assess the "outside the retail meter" energy requirements for a typical water system and how they fluctuate with changes such as those proposed above. Such a framework would require testing and validation using water systems whose energy requirements are unknown. It would have to provide estimates with an acceptable degree of confidence. Also, it would further an understanding of how energy requirements for water-related services behave or change under anticipated or common water supply and demand scenarios for the input system. To this end, a framework was developed that allows a user to estimate energy demand changes in response to reductions in end-user demand, end-use application, and reductions in surface water supply availability. In each of these commonly proposed scenarios, baseline data and observed fluctuations in energy usage are extrapolated into the future. The first proposed scenario incorporated into the study framework involves a reduction of end-user demand, as would be achieved with a successful water efficiency program. By analyzing how sensitive individual components and phases are to reductions in flows, the amount of energy saved congruent to a drop in end-use is estimated. The second scenario assesses the energetic effects of a conversion of untreated agricultural or secondary system water to municipal uses. Such a conversion would require additional pretreatment, distribution and wastewater effluent treatment. By analyzing the impacts of increases within these three phases of the water cycle, the energy demand increase congruent to conversions of usage is estimated. The third and final scenario incorporated into the study framework estimates the additional energy required to compensate for reduced surface water supply with other sources, such as an increased reliance on groundwater due to drought, climate change or reservoir sedimentation.

To achieve the study objectives, energy data taken from a large wholesale water supplier, its municipal customers, and the wastewater treatment facilities that receive their effluent, are synthesized. The data are subjected to analysis for key factors and components of the system that affect energy requirements for large water wholesalers, retailers and wastewater facilities. Using the parameters that are determined to be the best predictors of energy expenditure, a model is developed that estimates baseline energy usage for the water system in question. The baseline data is used to extrapolate energy requirement into the future under the aforementioned scenarios.

The following chapters describe the selection of the case study, gathering and synthesis of energy data, and the evaluation of system characteristics that strongly predict energy requirement for that water system. A validation of the model estimation capacity was conducted using several water agencies/municipalities whose extant energy requirement was unknown. The estimates were compared to the agency’s actual energy data once acquired. Scenarios for alternate water supply and demand, as described above, were then applied to the case study system, resulting in estimates for future energy requirement.

CHAPTER 2

METHODS

2.1 Overview

The methodology presented by this study involves acquiring utility data for a case study water system, including wholesale, retail and wastewater facilities. Each line item within the utility data is then categorized into the appropriate water supply cycle phase based on the facility description. Categorized data points are combined to derive an average energy factor, a value described in detail in the following section. Using the energy factors as a framework for assessing energy requirement by component, a spreadsheet model is created. A baseline energy requirement for the water system is estimated by multiplying water volume inputs from the user and the energy factors. The resulting spreadsheet model is tested by comparing the estimate to the actual energy requirement reported by the water agency. The spreadsheet model is then used to forecast energy usage into the future and answer the three scenario questions posed by the study.

2.2 Energy Factors

Preliminary steps of the study involve defining a mean value and a range of energy intensities or energy factors for each phase of the water cycle. Assuming other water systems have similar energy demand for similar types of components, generalized values for each phase can then be used to estimate the total energy demand for a water system, geographic or jurisdictional area. The energy factor is the proportion of each phase's energy demand (kilowatt-hours per year) to the water delivered, processed or consumed (acre-feet per year) by that phase. Dividing the annual energy demand by the corresponding water volume allows for comparisons on a per water unit basis (kilowatt-hour per acre-foot). If the energy factors for each water cycle phase are fairly consistent and uniform, they can then be applied to water systems whose energy usage is unknown or not readily available. Benchmarking of energy factors also enables a comparison of the relative efficiency of different system configurations, processes and technologies. This approach was initially presented by EPRI, the CEC, and even more explicitly by the National Resources Defense Council (NRDC) and the Pacific Institute. The "Water-to-Air" model presented by the NRDC in 2004 uses the energy factor approach to estimate energy requirement for a given water system and then calculate an estimate of GHG impacts with different energy mix scenarios. However, this study is different from the NRDC study and model, as it accommodates more predictive system component parameters, presents a refinement of the water cycle phase energy factors, and uses the system baseline energy estimate to model and predict energy requirement under future water supply and demand scenarios.

The ease or difficulty of determining energy factors from utility data is a function of whether the agency has a digital record of their energy usage, or whether the local utility company is willing to provide that data in a digital format. Once acquired, utility billing data can be extracted for a specified time interval and synthesized for analysis.

Each utility account line item is categorized into the water cycle phase that it most represents. For example, the energy used at an automated diversion gate would be categorized as “Source & Conveyance – Surface Water.” Groundwater well pumps would be categorized as “Source & Conveyance – Groundwater,” while a lift or booster pump station would be categorized as part of the “Distribution” or “Wastewater Treatment” phase. Each category is then analyzed for any predictive characteristics that may affect their energy requirement. An example is the depth to the water surface elevation of a well source within “Source & Conveyance – Groundwater.” Although, the energy required to pump groundwater varies, depending on pump size and efficiency, the total dynamic head or the elevation lift the pump must overcome is a strong predictor of how much energy will be required by the pump and for the category as a whole (CEC 2003). This was stated explicitly in the CEC’s 2006 revised report, where the units for the groundwater energy factor were altered to incorporate water surface depth – namely kilowatt-hours per acre-foot per foot of lift (CEC 2006).

It is helpful to refine the water supply cycle categories into sub-categories that are more specific, either by technology employed, geographic location or some other predictive characteristic. The energy use of some segments varies strongly with regard to geography, such as the “Source” and “Distribution” segments. Other phases vary with regard to the technologies employed. An example of the latter is the wastewater treatment phase, where the primary determinants of a plant’s energy use are the technology employed and the operating capacity. The functionality of the model presented in this study is based on energy factors that have been further subdivided with regard to these characteristics.

2.3 Energy Requirement Analysis Framework

To simplify the analysis of energy factor data, a framework is developed to calculate current and future energy requirements. Each segment of the water cycle is captured in a spreadsheet model that performs the calculation for the total energy used by the segment. It does this by multiplying the appropriate energy factor by the volume of water for that subcategory, as entered by the model user. Once all categories and sub-categories for a water system are entered by the user, they are summarized to arrive at an estimated systemwide annual total energy requirement. The values entered by the user generate an estimate of the system's baseline energy usage for that year. A low and high energy use estimate is also generated, based on the standard deviation of the category's energy factors, to provide a window of confidence in the model results.

Use of the model requires knowledge of the water system in question. Figure 2 provides an overview of the model process flow from user input to modeled scenarios. Primary inputs to the model include the volume of surface water imported by the system, groundwater pumped, spring sources, and all other sources for a given year. The user must also be acquainted with general technologies employed by treatment facilities, such as the design capacity and the volume of water treated. Other basic operational characteristics of the system can be selected for input into the model, such as whether

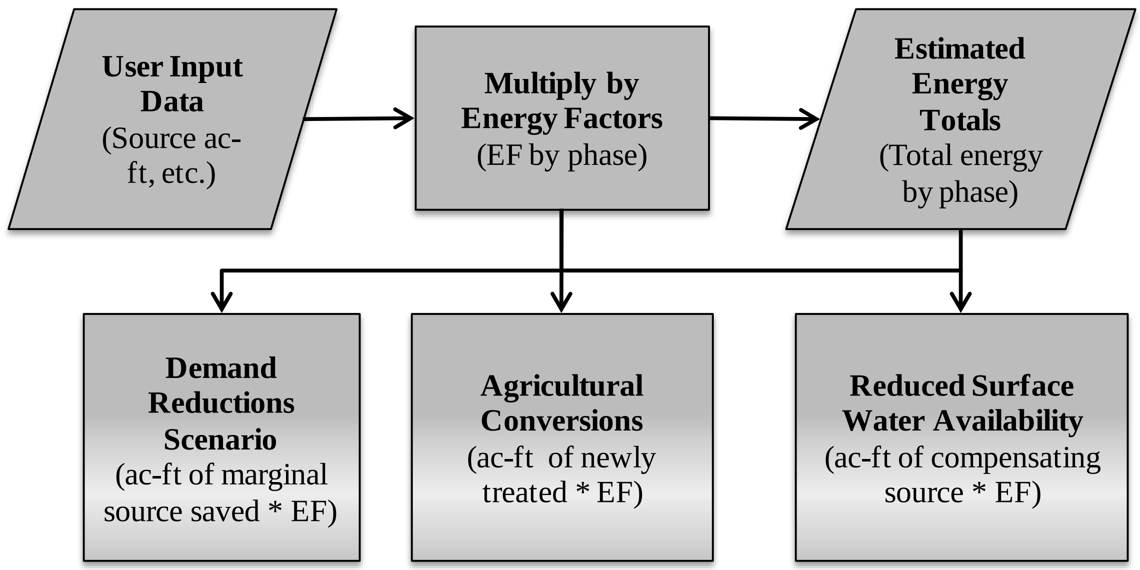

Figure 2. Overview of model processes

SCADA or cathodic protection is employed, how much water is distributed by booster stations or how much water flows through pressure reduction valves on the system. If a wastewater facility is part of the water system, information about technology employed, the design capacity and whether biogas is generated is also required. The model uses information provided by the user to determine which energy factor to apply to the volume of water delivered or treated by each listed facility. Once the parameters are entered into the model, they are summarized for the given year. Figure 3 provides an example of the formatting of the user interface of the model for required inputs concerning wastewater treatment.

A column of cells in the spreadsheet model are reserved for the user to manually enter energy requirement for any facility, if it is available. This allows for even greater accuracy of the total estimated energy figure.

Wastewater Treatment									
						Energy Use (kWh/Yr)			
	Type of Treatment Facility	AF/Year	Biogas?	Plant Capacity (MGD)	Use Estimate?	Estimated Low	Estimated Mean	Estimated High	Actual Use
1	Trickling Filter/Sewage Lagoon(1)	7,000	No	10 - 50 MGD	Yes	2,380,000	2,817,500	3,255,000	
2	Activated Sludge(1)		No	< 10 MGD	No				
3	Advanced Treatment(1)		No	< 10 MGD	No				
4	Advanced w/ Nitrification (1)		No	< 10 MGD	No				
5	Trickling Filter/Sewage Lagoon(2)		No	< 10 MGD	No				
6	Activated Sludge(2)		No	< 10 MGD	No				
7	Advanced Treatment(2)		No	< 10 MGD	No				
8	Advanced w/ Nitrification(2)		No	< 10 MGD	No				
	Total	7,000				2,380,000	2,817,500	3,255,000	

Figure 3. Model interface for user inputs

A function is also provided that allows the user to send the water system's actual energy usage to a study coordinator for input into a maintained database. The purpose of the database is to expand the dataset of known energy values for different types of facility components, based on their characteristics, geography and employed technologies, and to allow for energy factor refinement. Further refinement of subcategories of the water cycle phase increases user confidence in the methods and estimated results when it is used by water planners for research and development or as an adaptive management tool.

Once the model inputs are summarized, the user is asked to assess whether the system in question is nearer the low or high range values for total energy consumption. A selection of "Low" or "High" range is made based on the user's knowledge of the system. The user is asked to enter a depletion factor, used to calculate the additional wastewater effluent that will require treatment for the agricultural water conversion scenario. Once this is entered into the model, the user has access to all graphs that detail the calculated results of the alternate water supply and demand scenarios for both low and high range water systems. The user also has access to the underlying tables and calculated values of the scenarios via the “Engine” tab of the model, and to the underlying energy factors associated with different water system parameters.

2.4 Model Validation

The developed framework needs to be tested by comparing estimated energy to that reported by a series of water agencies or municipalities. A variety of systems are used in the validation step, ranging from small rural communities to mid-sized urban municipalities to larger water wholesale systems. They have a diversity of characteristics, from heavy reliance on groundwater withdrawals to surface water sources or local springs, and a wide range of applications such as agricultural, municipal and industrial use. The model is tested for municipalities and water agencies that are geographically or climatically similar to the system used to derive the energy factors before use on dissimilar systems. To complete the validation step, the components of each selected water system are entered into the model along with their water deliveries for a given year. The actual energy data are acquired from the system’s utility companies and compared to the values predicted by the model. The amount of error within the estimates predicted by the model is summarized. The selection of validation cities and the results of the validation step conducted for this study are discussed in the “Case Study” sections below.

2.5 Case Study

2.5.1 Background

The energy requirements to treat and convey water in Utah are not well understood and have never been quantified. Utah's annual snowmelt runoff and topography lends itself well to the state's water agencies and for this reason energy requirement for water, and also market costs, are thought to be relatively low. High-quality water from mountain runoff is collected and distributed via a system of gravity-fed canals and pipelines. The effect is to use gravity to pressurize the water distribution system, which minimizes pumping to move the water or to maintain constant water pressure. Some agencies, such as the Central Utah Water Conservancy District (CUWCD), Provo River Water Users Association (PRWUA) and Weber Basin Water Conservancy District (WBWCD), maintain hydropower facilities on these distribution networks, which they use to offset some of their own energy costs (Denos 2009, Hogge 2009, Tullis 2009). These systems are sometimes net energy producers.

In addition to these advantages, Utah's snowmelt runoff has remarkably high water quality and requires very little pretreatment, further reducing energy requirement (U.S. Geological Survey 2002). The above factors combine to make water one of the least expensive utilities paid for by residents – surprisingly lower than most of the rest of the United States. The average water user in Utah pays about $1.34 per thousand gallons, which is 43% less than the national average and 45% below the average for western states (Klotz 2009, Utah Foundation 2002). However, as Utah's population continues to grow, these inexpensive and less energy intensive sources of water are becoming rarer. Much of Utah's "easy" water – flows that originate from mountain ranges and can easily be diverted and treated – has already been developed and put to beneficial use. Major water projects on the horizon will require greater amounts of energy. Both the Lake Powell Pipeline and Bear River Development Projects will require long distance water importation and greater amounts of energy to lift water from remote sources to urban communities. Published reports on the Bear River Development Project refer to it as being, "Utah's last untapped water source" (Division of Water Resources 2005a). In addition to new water development projects, Envision Utah suggests that other water sources may include more extensive groundwater development within the safe yield of local aquifers, additional diversion and treatment of Wasatch mountain streams, agricultural irrigation conversions and water conservation. (Utah Governor's Office of Planning and Budget 2008). Water demand reduction and the efficiencies found with new techniques and methods of extracting and treating water can help reduce energy costs of future development. However, if it is true that Utah's easily developable water supplies are becoming rarer, then the issue of energy consumption within each phase of the water supply and consumption cycle will take on a new importance and play an increased role in the decision-making process.

2.5.2 Water Agency Types

Utah's residents are supplied both by water retailers and municipalities, large wholesalers, noncommunity systems and private wells. Understanding and estimating the energy demand for a typical system in Utah requires an examination of each type of system. Figure 4 illustrates a general progression of the water supply chain from the wholesaler to the end-user and back to the natural environment. Wholesale water agencies own and/or maintain larger conveyance systems that bring water from distant watersheds into major population centers, such as the Wasatch Front or Utah's fast-growing "Dixie" region. A typical wholesale system consists of surface storage conveyance facilities – such as reservoirs, diversions and pumps, water treatment facilities and an expansive distribution network of tunnels, canals and pipelines. These larger projects are the primary beneficiaries of Utah's geography via gravity-fed and distributed water systems. Water wholesalers may also have significant groundwater sources to complement other supplies. They are likely to have substantial existing infrastructure upgrades to fund, and larger capital improvement projects planned for the future. These entities may have the most energy savings to gain – not by implementing efficiency upgrades since their systems are already quite efficient – but by implementing targeted demand reduction programs that forestall expensive water development projects and by choosing future infrastructure options that minimize energy costs.

Unlike most wholesalers, water retailers own and maintain a smaller water system that serves water directly to end-users. These are usually smaller, nonprofit agencies such as water improvement districts, water user associations or municipalities. Aside from purchasing water from a wholesaler, they also operate their own springs and groundwater wells. They may pump or purchase additional water to meet peak demand

Figure 4. Generalized large water supply system distribution in Utah

over the summer months or to supplement supplies during periods of shortage. A typical retail water system consists of an array of smaller groundwater pumps, booster stations, chlorination facilities, meters and distribution networks that contribute to their overall energy demand.

Non-community systems supply water to areas that have transient populations or fewer connections than community systems, such as mobile home parks and campground sites. Their water use is estimated to be a little more than 10,000 acre-feet of water out of about 952,000 acre-feet of water used in the state of Utah (Klotz 2009). Private wells used to supply individual homesteads are also a relatively small percentage of the water used in the state. Quantification of requirements to supply noncommunity systems and private wells would be extremely difficult and is not included in this study. One other category of water provider and water usage is that of self-supplied industries. This category of water user withdraws approximately 209,000 acre-feet out of the above total – a significant amount. The water and energy requirements to withdraw and treat water designated for these industrial purposes is reported each year to the state’s regulatory agencies, but individual industry figures are not released to the public (Utah Division of Water Resources 2009).

2.5.3 Jordan Valley Water Conservancy District (JVWCD)

A major water provider in Utah and its member agencies were selected to represent a large water system that could provide a framework for an energy estimation model. Jordan Valley Water Conservancy District (JVWCD) is situated on the south-western quadrant of the Salt Lake Valley and has supplied an average of 118,000 ac-ft per year over the last 5 years to its member agencies and other smaller customers (JVWCD 2009). Member agencies are comprised of both municipalities and water retailers that in turn, supply and sell water directly to retail customers. Figure 5 is a diagram of a distribution relationship JVWCD has as a wholesaler, with its member agencies, customers and wastewater providers. JVWCD's water supply sources include imported water from the Uinta Mountains via tunnels, diversions and canals, which they also supplement with groundwater wells. Its geographic extent is large, but typical of a large wholesaler-to-retailer-system and serves as a good template for the model. Figure 6 is a map of JVWCD's service boundaries, selected member agencies and two wastewater facilities that treat the system's effluent. JVWCD's deliveries change over time due to fluctuations in pricing, water availability, demand and a growing customer base. The listing of member agencies for this case study was taken from the Utah Division of Water

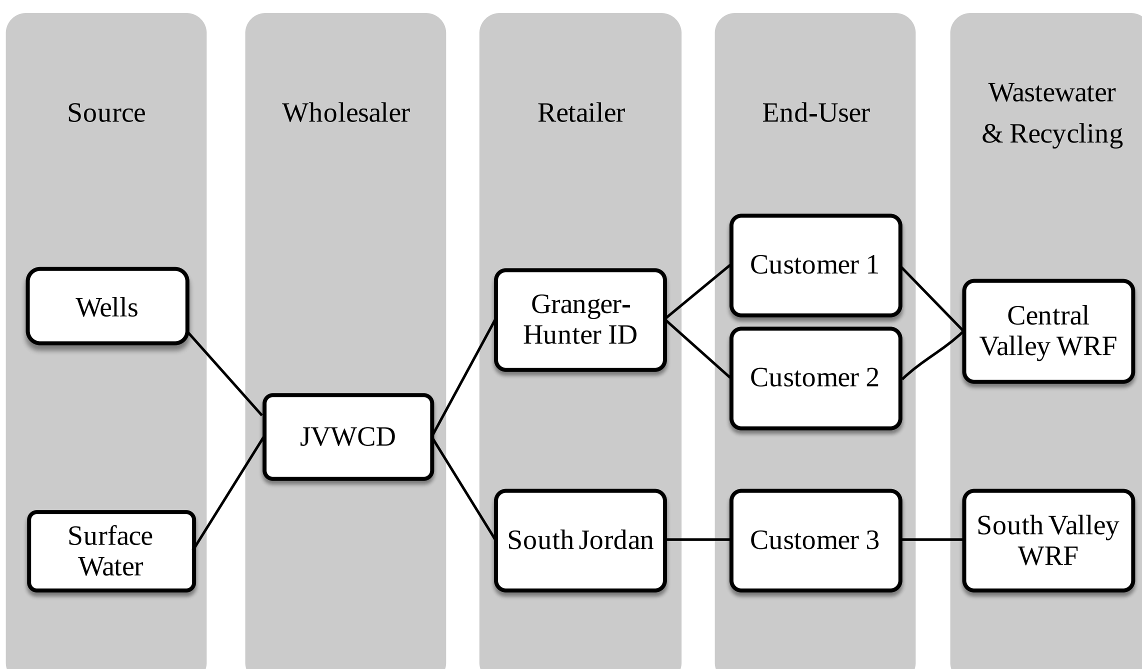

Figure 5. Generalized distribution diagram for the JVWCD system

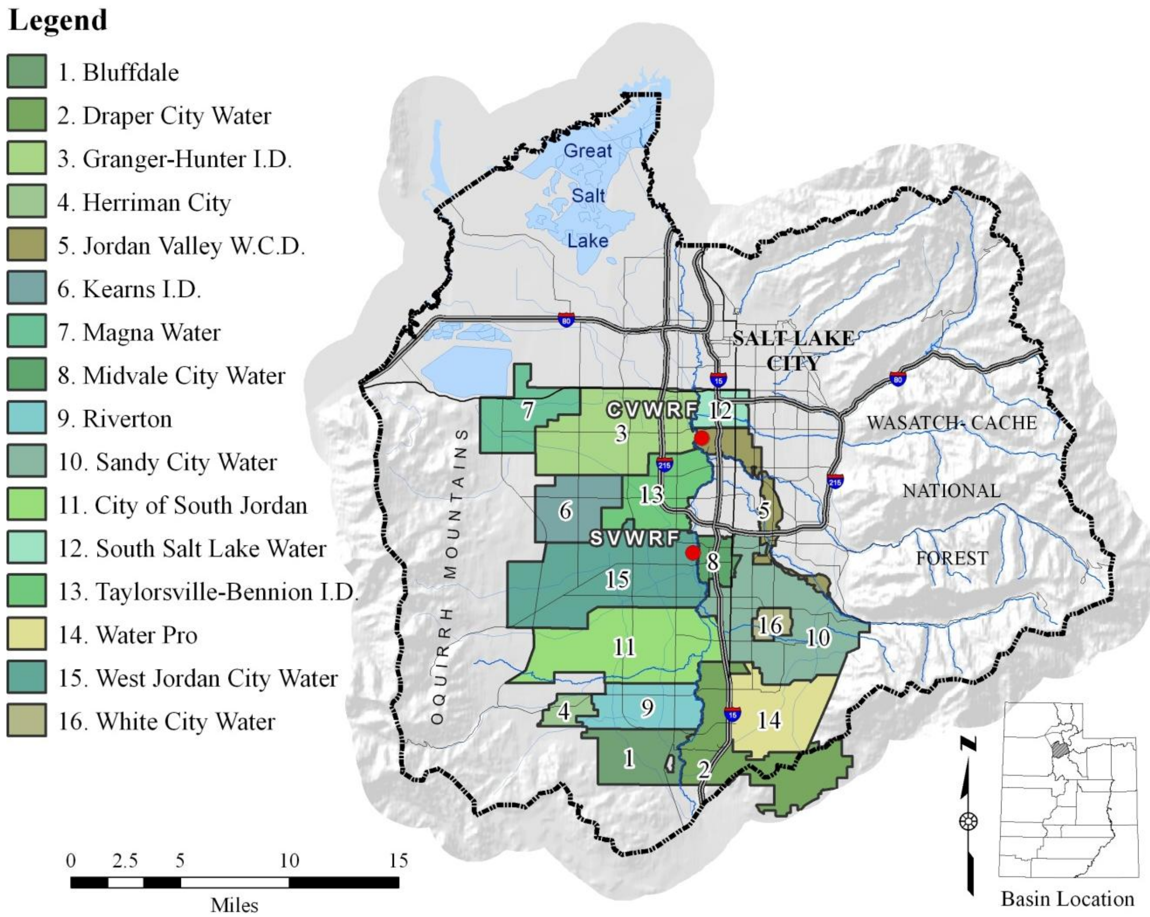

Figure 6. JVWCD service boundaries, selected member agencies and water reclamation facilities

Resource's "Municipal and Industrial Water Supply and Uses in the Jordan River Basin," (Utah Division of Water Resources 2009). Table 1 lists the member agencies selected for the study and the deliveries made to them (JVWCD 2009). JVWCD's smaller retail component was omitted as a member agency for clarity. Wastewater treatment facility data was acquired directly from the wastewater facilities themselves. Most wastewater treatment facilities are not dispersed like a municipal water system, and therefore usually have only a few utility account numbers to reference. Also, being such energy intensive facilities, they have a vested interest in continually monitoring their energy demand per volume of water processed. The two wastewater plants that service the surrounding area and municipalities within the JVWCD system are Central Valley Water Reclamation Facility (CVWRF) and South Valley Water Reclamation Facility (SVWRF). Both were readily able to provide their annual energy demand per volume of water processed. CVWRF identified their facility as a plant that employs advanced wastewater treatment without additional nitrogen removal. They use biogas generation as a moderate offset to their energy consumption and they also treat a small volume of water to tertiary standards for water recycling. This is used as supplementary irrigation for a nearby golf course. CVWRF's primary energy consumers on site were their influent lift stations at the head of the plant. Because of their configuration, they confirmed that reductions in demand, and hence reductions in plant inflows, resulted in a corresponding decrease in energy requirement and vice-versa.

Table 1. 2003 - 2009 Fiscal Year JVWCD water deliveries to selected member agencies

	FY 03/04	FY 04/05	FY 05/06	FY 06/07	FY 07/08	FY 08/09
Bluffdale City	1,278	1,137	1,420	1,573	1,574	1,410
Draper City	2,470	2,268	3,033	3,590	3,372	3,207
Granger-Hunter Improvement District	18,320	16,575	18,734	15,988	17,411	17,707
Herriman City	1,503	802	1,658	2,023	2,507	2,165
Kearns Improvement District	7,113	6,802	8,264	8,258	8,321	7,759
Midvale City	102	176	928	951	172	159
City of South Jordan	9,300	8,564	10,427	11,522	12,034	11,327
City of South Salt Lake	1,117	1,021	705	603	883	804
Taylorsville-Bennion Improvement District	5,479	5,256	5,012	3,955	5,354	5,005
West Jordan City	14,992	1,664	642	582	1,247	16,419
White City Water Improvement District	109	69	-	-	-	-
Subtotal - Selected Member Agencies	61,783	44,334	50,823	49,045	52,875	65,962
Other Wholesale Deliveries	6,832	16,469	19,322	19,709	21,099	4,628
Total Wholesale Deliveries	68,615	60,803	70,145	68,754	73,974	70,590

*all deliveries in acre-feet

SVWRF categorized itself as a facility that employs advanced treatment with an additional nitrification and de-nitrification processes. They also employ ultraviolet radiation and ozonation for their disinfection process. Their primary energy consumers are the aerators and biosolid dryers that must be kept at a full-power state regardless of variation in inflow. As a result, SVWRF's energy requirement is almost twice that of CVWRF for the same volume of treated water. The energy requirements provided by plant operators were used to estimate the energy factors for these two treatment technologies, but energy factors for others were extracted from the NRDC report (Wolff 2004).

2.5.4 Case Study Data Synthesis and Analysis

Each water district, member agency and validation city/agency that agreed to participate in the case study was asked to make a data request to their local utility providers, including electric and natural gas utilities, for any water-related service accounts. Once sent in, these requests were coordinated by utility staff and a database query was run for each agency for the study period of 2004 to 2008. The database query extracted each account and line item, including the site description and the annual kilowatt hours of each facility component. The query data given to the water agency were then forwarded to the study coordinator. Each line item was checked to ensure that it was indeed part of the city or agency's water system, as opposed to a park light or other municipal service. Each water facility line item was then catalogued into the most applicable water supply cycle phase. An average of each agency's annual kilowatt hour demand within each phase was calculated and compared to that of other agencies. Tables for comparison between agencies can be found in the Appendix.

The volumes of water related to the energy cost were taken from the Utah Division of Water Right's website, unless they were reported directly by the member agency (Utah Division of Water Rights 2009). JVWCD also provided a summary of water usage and delivery estimates for themselves and all of their member agencies. These were compared to the volumes of water delivered as reported on the Division of Water Right's website and were found to be consistent in most cases. Where there were discrepancies, the value reported by JVWCD was used, as it was deemed to be more consistent. The water supply values were further categorized as originating from imported surface water, groundwater or another local source, such as a spring. The energy used by facilities dedicated to surface water sources and conveyance was then divided by the volume of water diverted from that source. Similarly the energy used by facilities dedicated to groundwater pumping was divided by the volume of water extracted from groundwater sources, to arrive at an energy factor for these subgroups of the "Source & Conveyance" water cycle phase.

Water treatment facilities within the JVWCD systems were categorized by design capacity. The energy consumption for the treatment facilities was then divided by the total amount of water treated. In JVWCD's case, the amount of treated water constituted approximately 75% of their total water supply and deliveries, with the remainder allocated for agricultural purposes (JVWCD 2009). Facilities related to distribution costs, such as meters and booster stations, were summarized and divided by the total volume of water transported or delivered by JVWCD or the member agency in question.

The wastewater treatment plants within the JVWCD system were classified according to their treatment capacity and their method of wastewater treatment (Fisher 2009, Hedges 2009). Annual energy data, including electricity, natural gas and biogas estimates, were retrieved for both facilities for the period of analysis. The net energy total (energy used minus generated biogas energy) was divided by annual plant flows for both wastewater treatment facilities to determine the energy factor for each plant. The energy factor for the JVWCD system was calculated as an average of these two values, weighted by the number of member agencies that supplied each plant with its effluent.

After the calculation of all energy factors for JVWCD (the wholesale district only) and all member agencies, they were compared to each other by type of system and by category. For example, JVWCD's total energy consumption was compared to member agency totals within water cycle phases to see if there was a difference between a largely gravity-fed wholesale system and a small retail system. Similarly, JVWCD's unit energy demand within each water cycle segment was compared to member agency unit energy demand. Annual energy factors for the wholesale district and the member agencies were combined to calculate a systemwide average for each water cycle phase. These results were compared to the energy factor values estimated for the water supply cycle in California's original and updated CEC reports (CEC 2005, CEC 2006).

Other analyses conducted include a statistical analysis of the relationship of surface water supply and groundwater withdrawals. The imported surface water and groundwater extracted by JVWCD for the period of 2001–2008 were analyzed to determine if any correlation existed between reduced surface storage availability and increased groundwater withdrawal. The time period analyzed incorporated the majority of a drought experienced locally that began in 2000 and ended in 2005. The data were also analyzed with regard to other factors that may impact groundwater withdrawals, such as precipitation and the net evapotranspiration rate (ET_{net}) experienced in the basin.

The volume of untreated water delivered by JVWCD was analyzed with regard to its possible conversion to a municipal and industrial use. An assumption was made by the model that agricultural water was of sufficient quality that it could be treated using conventional culinary water treatment methods. Estimates of how much additional water would need to be treated and distributed were calculated with each percentage conversion of untreated water. Similarly the additional amount of influent to be treated by a wastewater facility was estimated based on an assumed indoor end-user depletion rate of 20%. This percentage was used based on the indoor use and return flows reported by each agency in the *Municipal and Industrial Water Supply and Uses in the Jordan River Basin* report (Utah Division of Water Resources 2009).

The energy factors for each water source for the JVWCD system were analyzed to determine the order of each in terms of marginal use. One of the assumptions made by the model is that the most marginal source of water will be eliminated with reductions in demand, followed by the next most expensive source. The volume of water saved by percentage reductions in demand was calculated with regard to reductions in the most marginal sources of water sequentially and the resulting volumes multiplied by their respective energy factors to arrive at an energy cost savings for each increment. The results of the methodology proposed by the study are visited in greater detail in the "Results and Discussion" chapter.

2.5.5 Case Study Model Validation

To further validate the model, system information for JVWCD and its member agencies was input into the model and the results included in an error assessment. These systems were used to derive the energy factors and to create the framework for the energy estimation model. In addition to testing the results for JVWCD and its member agencies, three water agencies/municipalities were selected for model validation. These additional systems are climatically similar, but are geographically dispersed and characteristically different from JVWCD and its member agencies. The first system selected for the extended model validation is Delta City, Utah. Its population relies entirely on groundwater sources and treats at the extraction site with chlorine. They also have a simple distribution systems and sewage lagoon wastewater treatment facility. It is a good example of most small and rural community water systems in the region. The second system selected for model validation is Logan City, Utah. Its population of about 50,000 relies heavily on local springs with a small supplement of groundwater. They also treat their water at the source site with chlorine. A large sewage lagoon system serves the population’s wastewater treatment needs. The third system selected for model validation is the Washington County Water Conservancy District (WCWCD). This agency serves a much larger population of approximately 160,000 with a variety of water sources – surface water importation, groundwater, springs and recycled water. They have large state-of-the-art water treatment and wastewater treatment facilities and an expansive distribution system.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Energy Factors

The utility and water supply data gathered from JVWCD the wholesale district, the member agencies, water treatment facilities and wastewater treatment facilities within JVWCD's service boundaries were categorized and analyzed to create a composite energy factor. The resulting percentages of each energy factor for the JVWCD system, including the wastewater facilities, which are separate entities, are portrayed in Figure 7. It is a comparison of the per acre-foot energy cost of each water cycle segment. The percentage of energy for recycling water is omitted because it is relatively small (0.6%). The figure shows that the bulk of the energy used per acre-foot is for groundwater withdrawals and wastewater treatment. Given JVWCD's ability to procure surface water from energy efficient, gravity-fed systems, this is a reasonable distribution of energy costs. The actual values for each energy factor and the standard deviation (STDV) for each water cycle phase and subgroups within the "Source & Conveyance" category are summarized in Table 2. The largest energy consumption phases are for groundwater withdrawal and wastewater treatment. This is followed by distribution costs, surface

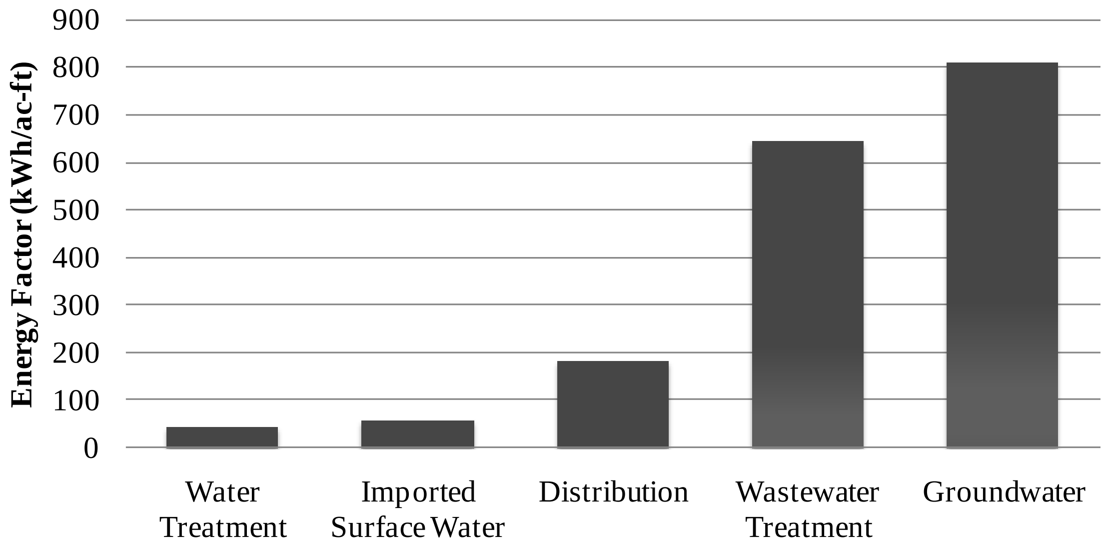

Figure 7. Comparison of energy costs by water cycle segment of the JVWCD system

Table 2. Energy factors for water cycle phases within the JVWCD system.

Water Cycle Phase	**Energy Factor (kWh/ac-ft)**	**STDV**
Source & Conveyance Facilities		
Surface Water (n = 235)	56	±45
Groundwater (n = 495)	817	±128
Recycled Water (n = 1)	10	
Water Treatment (n = 10)	42	±3
Distribution (n = 960)	180	±37
Wastewater Treatment (n = 2)	643	±221

* Wastewater treament STDV is due to different wastewater treatment technologies and design capacity differences.

water importation and water treatment respectively. A full tabular breakdown of the wholesale district and each agency's energy factor is included in the Appendix.

When compared to the energy factors presented in the CEC's 2005 report and the revised 2006 figures, JVWCD's energy intensity is generally comparable in most categories. Energy requirements for groundwater withdrawal, distribution and wastewater treatment are comparable at the lower ranges. Major departures from the CEC's evaluation are for surface water importation, initial water treatment and water recycling. Table 3 shows the energy factor ranges for each water cycle phase for both JVWCD and those estimated by the two CEC reports. Some categories were excluded from the CEC 2006 updated report, but these refined estimates include additional allowance for system-wide losses and revisions based on a review of the methodologies used in the 2005 report. Again, JVWCD's system is comparable in most categories, but substantially less in others, reflecting its geographic advantages. The broadness of the ranges, both for JVWCD and the CEC, reflect the limitations of utility data gathering and

Table 3. JVWCD's energy factors compared to the CEC 2005 report and 2006 revisions

Water Cycle Phase	**JVWCD EF Range (kWh/ac-ft)**	**CEC 2005 EF Range (kWh/ac-ft)**	**CEC 2006 EF Range (kWh/ac-ft)**
Source & Conveyance Facilities			0 - 4500
Surface Water	0 - 100	0 - 3500	
Groundwater	700 - 950	600 - 950	
Recycled Water	10	130 - 400	
Water Treatment	40 - 50	30 - 5200	30
Distribution	140 - 220	230 - 400	400
Wastewater Treatment	400 - 850	360 - 1500	400 - 700
Recycled Water Distribution			400 - 1000

*Does not include desalination or other sources not used in JVWCD's system lack the specificity of a geographically or jurisdictionally regionalized dataset. Further disaggregation of the categories into subgroups, as well as more empirical and calculated water facility data, is needed to narrow the range of values within each energy factor.

3.1.1 Energy for Source and Conveyance – Surface Water

Surface water sources comprise 81.3% of total water withdrawals made in Utah (U.S. Geological Survey 2009). This percentage includes those made for irrigation of agriculture, which is by far the largest end-use diversion – as opposed to depletion – of water for any end-use sector. Within the JVWCD district, the percentage of water supply from imported surface water is also quite high – about 91% over the study period. The remaining 9% of water supply is pumped groundwater (JVWCD 2009). Reliance on surface water decreases to 75% when member agency water sources are figured into the above. This is larger than the statewide average of 45% reliance on surface water by public water suppliers, reflecting the abundance of inexpensive surface water procured by JVWCD (Utah Division of Water Resources 2005b). The imported surface water energy factor related to the JVWCD system (0 – 100 kWh/ac-ft) is comparable to the lower end of the CEC's ranges. The upper limit of the CEC's ranges, at 3,500 and 4,500 kWh per ac-ft, indicate the high energetic costs of surface water pumping required in that region. The CEC acknowledges the energy efficiency of primarily gravity-fed systems by keeping zero as the lower value of the surface water range. In fact, installed hydropower facilities may generate greater amounts of energy than consumed on such systems. Energy factors for these would theoretically be negative and could be used to offset the energy used in other portions of the water cycle. Water systems that are adjacent to that of JVWCD take advantage of their hydropower facilities to sell energy back to the local power grid (Denos 2009, Devey 2009, Hogge 2009).

Another reason the JVWCD range is low is that their energy usage by surface water facilities procure only a portion of their total surface water supply. Each year JVWCD also purchases large volumes of water from yet other water wholesalers who pass their energetic costs along in the form of water pricing. Without also doing extensive analysis of all interrelated water systems, it is difficult to arrive at a perfect estimate for imported surface water. For the purposes of this study, these additional waters are included in the total surface water provided, which is then divided by the total energy used by JVWCD's surface water facilities. After a review of the hydropower generation upstream of JVWCD's procurement, it is likely that the energy factor range would be reduced further, resulting in zero (as it is currently set) or negative values.

Conveyance infrastructure that provides water to the JVWCD region diverts snowpack runoff from the high Uinta Mountains to the east and spans hundreds of miles. Most of the conveyance energy costs are for simple telemetry, measurement and control devices such as SCADA systems, diversion gates, and debris screens. The total energy required to operate this equipment is small when compared to the volumes of water conveyed by them.

3.1.2 Energy for Source and Conveyance – Groundwater

As stated above, groundwater comprises a smaller portion of the water delivered within the JVWCD system including member agencies – only 25% compared to the statewide average of 55% (JVWCD 2009, Utah Division of Water Resource 2005).

Some member agencies find that groundwater withdrawals are a better water source for their systems and rely on them almost entirely. EPRI estimates that groundwater sources are generally more energy intensive than surface water sources by 30%, but this study finds that the difference in energy requirement for these sources within the JVWCD system is much higher – about seven times more so than the neutral or energy-producing surface water sources in Utah (EPRI 2002). When compared to the CEC groundwater energy factor, JVWCD's is slightly higher. The NRDC's report estimated groundwater depths for three different areas in California, ranging from 120 to 200 feet (Wolff 2004). The groundwater depths in the Salt Lake Valley are of a similar range, but wells are drilled to 400 feet or more (JVWCD 2009, U.S. Geological Survey 2009). Variable water surface levels within aquifers may explain the higher energetic cost of pumping groundwater for the case study. The proportions of surface water to groundwater deliveries vary with climatic conditions, such as surface water availability, precipitation received, and how hot and dry the summer tends to be for a given year. Energy rates and groundwater availability (as well as aquifer yield safety) are assumed to also play a decision-making role for water managers as well, and these may become increasingly important in the future.

There are some significant cost differences in groundwater withdrawals when comparing water wholesale entities to small retail entities. These become even more pronounced when the wastewater segment, which is post-end-use and overseen by separate agencies, is removed. For example, though groundwater is not JVWCD's largest water source (only 9% of the total) it is by far its largest energy consumer per acre-foot. Pumping of groundwater averages 26% of total energy expenditures during the study period for JVWCD, the wholesale district. Figure 8 contains a breakdown of each year's percentage of groundwater versus the total supply, compared to the energy used by groundwater versus the total energy used from 2004–2008. JVWCD's member agencies, the smaller retailers in the system, rely more heavily on groundwater, and spend more of their energy budget to pump it. On average member agencies relied on groundwater for 28% of their water supply at an energetic cost of 57%. This annual distribution is shown in Figure 9.

The difference in the two distributions of groundwater and energy versus the total water supply and total energy suggest that wholesale water entities may have groundwater pumping facilities that are less efficient and they are likely to feel the impact of drought and reduced surface water availability first. Also, as the ratio of energy they

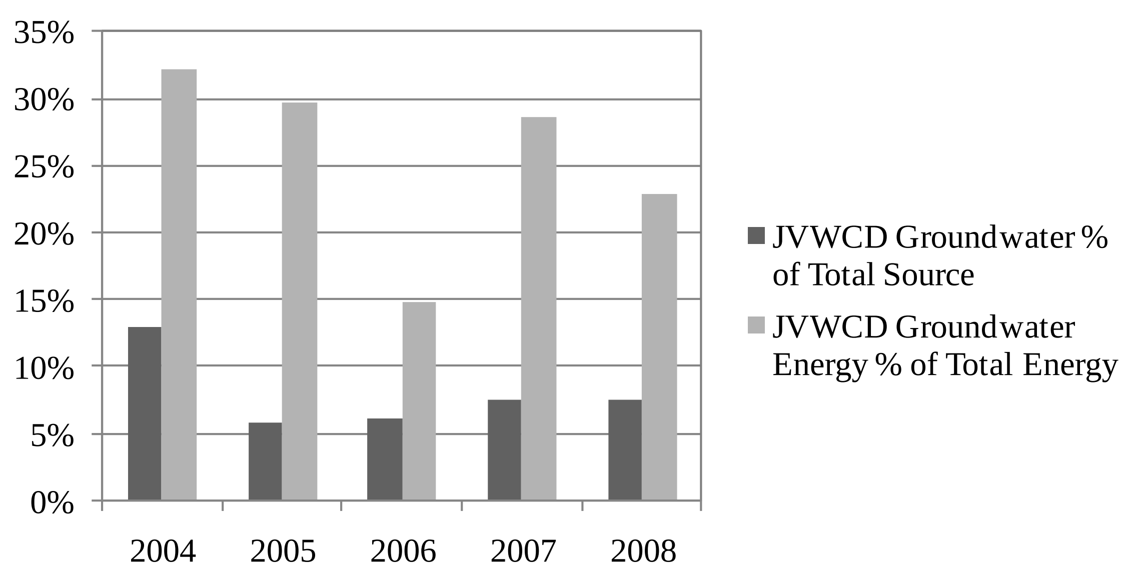

Figure 8. Comparison of the percentage of groundwater supply to total supply and groundwater energy to total energy for JVWCD wholesale system.

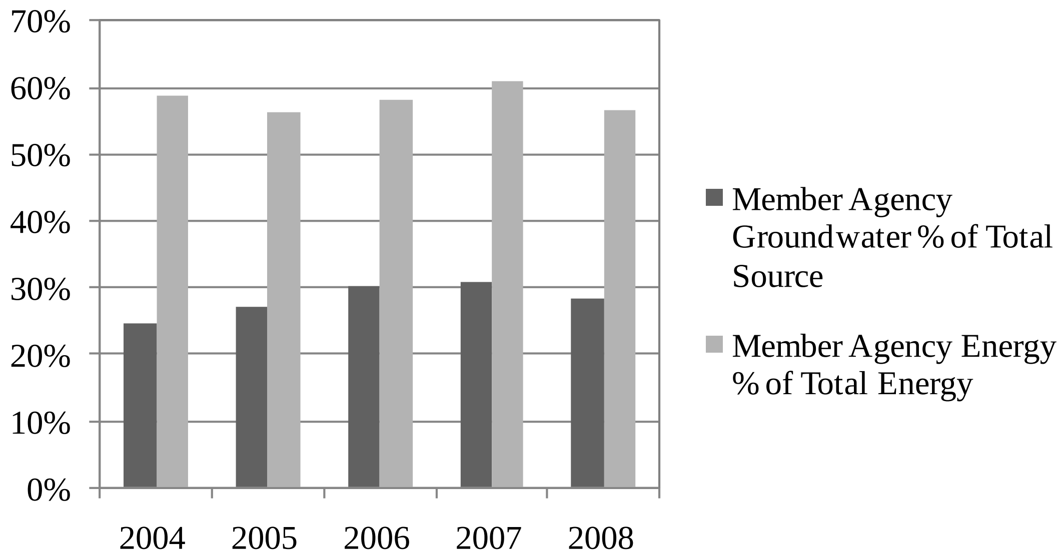

Figure 9. Comparison of the percentage of groundwater supply to total supply and groundwater energy to total energy for member agencies.

require per unit of groundwater (1:3) is higher than those of member agencies (1:2), any need to use groundwater to compensate for reduced surface water is likely to have greater impact on a wholesale entity in both energy and financial terms.

Other sources of water supply discussed in the CEC reports are not used or are much less common for JVWCD. Desalination has not been considered as a source of water because of readily available and much less expensive surface and groundwater supplies. Water reuse and recycling projects are being proposed in the region but have not yet become a significant supply option (Utah Division of Water Resources 2005c). Public perception of recycled water, concern for human health, environmental impacts, economics and legal hurdles are all factors with regard to its use. CVWRF is the only agency within the JVWCD system that is recycling any water, and the energy required to do so is minimal. However, as recycled water becomes a more valuable resource, the initial costs of added distribution networks and pumping will increase its energy factor. The revised 2006 CEC report includes this added cost explicitly by adding it as a water cycle segment and giving it an energy factor value of 400 – 1,000 kWh/ac-ft.

3.1.3 Energy for Water Treatment

JVWCD's water treatment energy costs are much lower than the CEC's estimated range – as they include extensive treatment of brackish and saline groundwater. Utah's snowmelt runoff has remarkably high water quality, and groundwater from deeper aquifers also requires very little treatment to meet drinking water standards. In areas where groundwater is impaired, it is often blended with higher-quality water from other sources to meet regulation standards. The JVWCD system has two water treatment plants, Jordan Valley Water Treatment Plant (JVWTP) and Southeast Regional Water Treatment Plant (SERWTP), with a combined design capacity of 200 MGD. Actual flows through both plants averaged 68 MGD in the 2008/2009 fiscal year with a maximum flow of 166 MGD. Retail water providers also have small-scale chlorination facilities to disinfect water within their systems, but these are usually tied to a distribution system feature such as a booster station or a groundwater well house. This makes small-scale treatment and disinfection energy costs difficult to determine.

3.1.4 Energy for Distribution

The smaller distribution energy factor range for the case study is also a reflection of the efficiency of regional gravity-fed systems. JVWCD's distribution system is comprised of booster stations, metering vaults, pressure reduction valves and cathodic protection (any facility contributing to conveyance of water through a distribution network). Almost all facilities in this category are minimally energy intensive. The main exceptions are booster stations that lift or pressurize water in the network. The average dynamic lift of JVWCD's booster stations, is almost 270 feet, with a cost of over $900,000 annually to operate (JVWCD 2009). Using small micro-turbines in place of pressure reduction valves might be an attractive option for entities that have high distribution costs (Ramos 2007, Smith 2008).

3.1.5 Energy for Wastewater Treatment

Wastewater treatment is the second most energy intensive phase of the water cycle presented by the case study. It requires between 450 kWh/ac-ft and 875 kWh/ac-ft depending on the wastewater facility to which the effluent flows. The energy factor presented for the case study is the average of these two facilities weighted by the proportion of agencies that send effluent to each. Because they receive inflows from municipalities outside the case study, the inflows to the plants from case study agencies were estimated based on the water supplied to each member agency, multiplied by an indoor depletion rate of 20% (Division of Water Resources 2009). The depletion is the amount of water used consumptively indoors during the end-use phase. The remaining water received by collection systems is then conveyed to wastewater treatment plants.

Both wastewater treatment plants in the case study are state-of-the-art facilities with advanced treatment and both are large enough to take advantage of the efficiencies present in economies of scale. CVWRF has an additional energy recovery step in an anaerobic digestion process. The resulting methane gas is mixed with natural gas to power five engine generators at the plant. This cuts back on utility costs at the site. The second plant, SVWRF, has a lesser capacity and requires greater energy than its northern counterpart. A bio-reactive aeration phase is the largest consumer of energy, followed by solids drying and disinfection. SVWRF has an additional nitrification phase that is more energy intensive and does not have any cogeneration capabilities due to local ordinances (Hedges 2009).

Personal communications with both plant managers indicated that increased water quality standards are at the forefront of their concerns. They anticipated more stringent effluent treatment standards in the very near future and the necessity of updating plant infrastructure to meet them. CVWRF indicated that they had additional space to install treatment facilities, but that it would be costly both energy-wise and financially – to remove added nutrients, phosphorus and micro-pollutants. SVWRF already has the ability to treat for removal of some nutrients, but lacks significant additional space if new facility buildings are necessary.

3.2 Results of Model Validation

The results of the validation step gave confidence that the model could be used to estimate the baseline energy of a water system whose current energy usage is unknown, but also highlighted portions of the model that need further refinement. Some segments of the water cycle were predicted more accurately than others and additional parameters are needed to adjust for the size of the water system being modeled. Additional instruction and clarification was needed by the agencies concerning the function of the model and its inputs.

To verify that the model could be used on systems similar to JVWCD (only the wholesale district), its own facility and water delivery data for 2008 was entered into the spreadsheet model. The estimated value of 38.7 million kWh overestimated the system's actual energy usage of 31.7 million kWh (18.1%). The error is derived by dividing the mean estimated energy and the actual energy reported by the agency. JVWCD's error is relatively high because the mean incorporates the higher range values. This is unfortunate in JVWCD's case since their actual energy usage for their largest source – surface water – is near to zero. Including the higher range of the surface water source adds approximately 10 million kWh to the high energy estimate, pulling the mean up as well. Without the additional 10 million kWh the error of the JVWCD estimated mean falls to 5.7%. Greater overall accuracy for baseline energy estimation could be achieved by incorporating a function into the model that allows the user to designate the water system as primarily gravity-fed and thereby eliminate the inclusion of the upper range.

The individual member agency water system and delivery data for 2008 were also entered into the spreadsheet model. The resulting estimates varied to a greater degree. Most systems were within a margin of error of 10%, but varied up to 127.1% for one member agency. This most inaccurate estimate for Draper City, Ut. was investigated and the city was found to employ four large booster stations – the likely cause of the model's under-prediction. The booster stations are used to lift large amounts of water up to an upscale community above Draper, called Suncrest, Ut. The elevation difference between the two cities is approximately 1,200 feet. This is a significant lift that contributes to Draper's high distribution costs. The other most erroneous estimate was for the City of South Jordan. In this case, the model over-predicted energy usage by 92.8%. South

Jordan purchases all of its water from Jordan Valley Water Conservancy District and therefore has no groundwater costs typical of other member agencies. Their distribution network is primarily gravity-fed as well. In this respect the results are similar to those of JVWCD's, such that the incorporated high range of surface water and extra distribution costs pull the estimated mean for the City of South Jordan higher then it would be otherwise.

The first of the geographically dispersed validation cities, Delta City delivered very few data points, indicating a simple water conveyance, treatment and wastewater treatment system. The energy estimation model over-predicted energy requirement in all categories for this smaller system. The range indicated by the model was 624,800 kWh to 1.1 million kWh and a mean of 842,300 kWh. This was 34% higher than Delta's actual energy requirement of 559,102 kWh. Logan City's water system delivery data were input into the model spreadsheet for an estimated range between 9.3 and 14.7 million kWh. The estimated mean was 12 million kWh, which was 10% greater than Logan City's actual energy usage of 10.8 million kWh.

Washington County Water Conservancy District (WCWCD) had by far the most complex water system, characterized by a myriad of water sources, treatment, wastewater treatment and water recycling. The wide distribution of WCWCD's water system is such that they are provided power by no fewer than four utilities. Gathering energy data from so many sources underscores the difficulty of assessing energy costs from year to year on a larger water system. The actual energy reported by WCWCD of 18.9 million kWh fell within the predicted range of 11.7 to 19.4 million kWh and deviated from the estimated mean value of 15.6 million kWh by 21%. When reviewing the WCWCD estimates, the category for recycled water was significantly under-estimated. It was discovered that a new distribution system had been recently installed throughout the surrounding community to convey the recycled water back to a point of use at a higher elevation. The energy factor applied to the volume of recycled water by the model was derived from the small amount of water recycled by CVWRF – a smaller value that does not incorporate any redistribution costs. Based on the actual energy value reported for WCWCD for recycled water, it is estimated that the energy factor should have been closer to 500 kWh/ac-ft, as opposed to the range of 10–50 kWh/ac-ft. Despite this discrepancy, the system total is still within the estimated range of values. When the estimate is adjusted to exclude the water recycling category, the error between the estimated mean and the actual energy usage falls to 14%. Table 4 provides a summary of the low, high and mean estimate, the actual energy usage reported for the study year and the error of the mean

Table 4. Summary of results of model validation step

Water Agency	Low Estimate (kWh)	High Estimate (kWh)	Mean Estimate (kWh)	Actual (kWh)	Error
Logan City	9,282,428	14,680,875	11,981,652	10,801,617	10%
Delta City	624,800	1,059,800	842,300	559,102	34%
Washington County WCD	11,725,146	19,450,195	15,587,671	18,880,158	-21%
Draper City	727,821	1,569,810	1,148,816	2,608,506	-127%
Granger-Hunter ID	9,508,120	15,033,800	12,270,960	11,605,661	5%
Herriman City	2,093,078	3,109,780	2,601,429	2,345,107	10%
Kearn ID	1,948,446	3,785,740	2,867,093	4,090,459	-43%
Midvale City	1,864,550	2,717,240	2,290,895	1,571,033	31%
City of South Jordan	2,195,397	4,735,170	3,465,284	249,602	93%
City of South Salt Lake	1,525,550	2,244,640	1,885,095	1,724,478	9%
Taylorsville-Bennion ID	8,398,000	11,685,440	10,041,720	9,950,343	1%
West Jordan City	5,114,278	8,951,780	7,033,029	6,306,638	10%
White City WID	2,949,100	3,898,720	3,423,910	3,775,330	-10%
Jordan Valley WCD	26,423,524	50,944,160	38,683,842	31,676,328	18%
Summarized Error					19.7%

Used to Develop the Model   Model Applied to System estimate.

Overall the energy estimation model performed moderately well at predicting energy requirement for medium to large sized water systems, with a cumulative error of 19.7%. The model tended to over-estimate energies for very small water systems and those that take significant advantage of gravity-fed conveyance. Further refinement of the energy factors, with the possible inclusion of the number of connections and recycled water redistribution costs as model inputs, would likely improve results as well.

3.3 Energy Impacts of Demand Reductions

To analyze how the case study would be affected by the alternate water supply scenarios discussed above, the inputs for JVWCD the wholesale district, (excluding member agencies and wastewater treatment), were entered for 2008 into the spreadsheet model as stated above. The estimated values were checked against the actual energy consumption provided by the utility agency and were found to be well-matched with the lower range adhering more closely to the actual energy usage reported by JVWCD. Therefore, the lower range scenario results were selected for viewing. The model automatically generated the results of each water supply and demand scenario in the form of a graph displaying future energy requirement.

The demand reduction scenario evaluates the effects of incremental reductions in the volume of water used by every segment of the water cycle. It is predicted to lower the total energy requirement for each water cycle based on the per unit energy cost of an acre foot of water; however, this does not imply that all sources and treatments are reduced equally. Source water volumes are reduced sequentially from the most marginal source of water first. For example, if a water agency uses a combination of surface water, groundwater and desalination to meet the demands of its population and it experiences a reduction in demand, the most expensive source of water – that of desalination – would be the first to be reduced. The model evaluates what the most marginal source of water for the system is, and, with each percentage of demand reduction, calculates the energy saved. Figure 10 shows the results for the JVWCD wholesale district when a 0%–35% reduction in demand is introduced as a future scenario. The results show a significant amount of energy can be saved with a 10% reduction in demand, which would curtail the use of groundwater pumping – the most marginal and energetically expensive source of water. Specifically, this would allow for an energy savings of 6.5 million kWh each year between the "Groundwater – Source

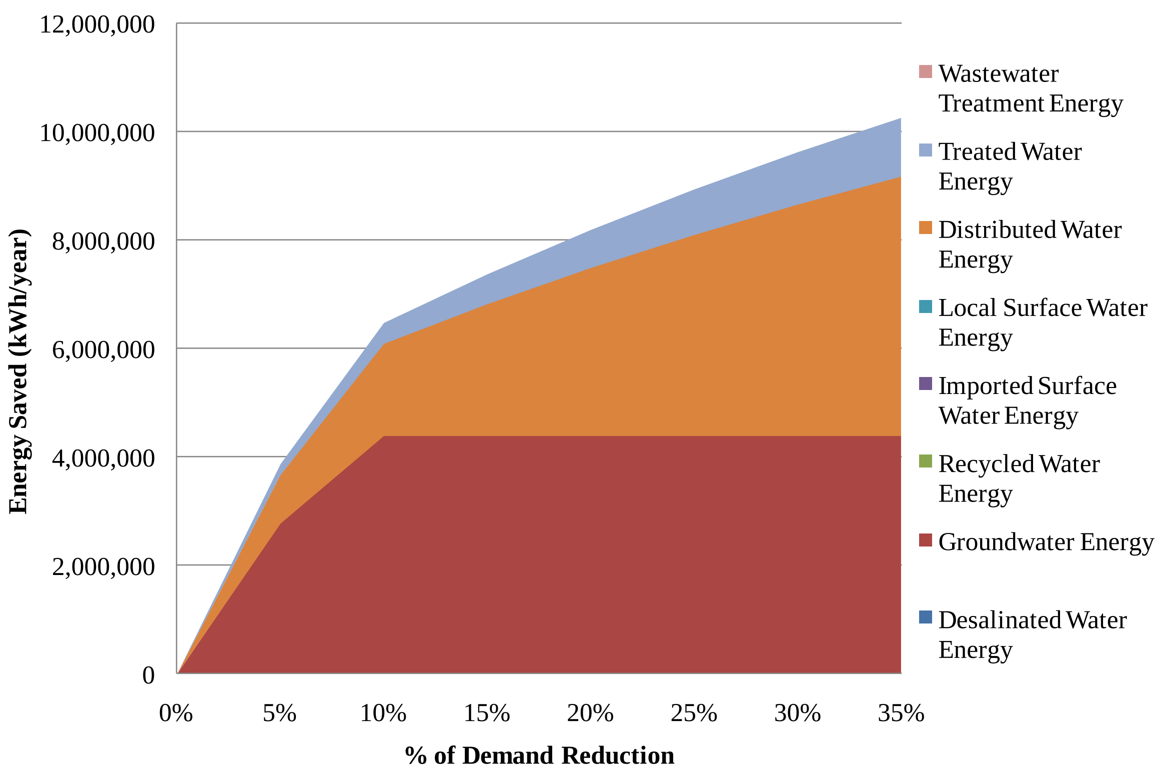

Figure 10. Saved energy for JVWCD wholesale district with reductions in demand.

Conveyance," "Distribution" and "Water Treatment" phases. When demand is reduced beyond 10%, the energy used in the "Distribution" phase is saved even more, and there is a small savings in water treatment energy costs. The State of Utah's public use water conservation goal is to achieve a municipal and industrial per capita demand reduction from 2000 levels of 25% by 2050. If this goal is met by the JVWCD using 2008 as a baseline year, it will save an estimated 8.9 million kWh per year. If demand is reduced to 35%, 10.3 million kWh would be saved annually. Interestingly, as the lower range energy factor for surface water sources is "0", any demand reduction applied to this category result in zero energy savings. If the high range results are viewed, the energy savings from surface water importation appear on the graph. Another water cycle segment, wastewater energy savings, is absent from the graph because the JVWCD wholesaler entity is the system being analyzed.

It is likely that, were JVWCD to experience significant demand reductions, many decision factors would come into play as to what water sources would actually be reduced. The legal ramifications of not putting a water right to "beneficial use" for a specified period of time would certainly influence water managers in exactly where to accommodate reductions. However, evaluating the impacts of reducing the most energetically expensive source of water is still a useful exercise and reveals how much energy can theoretically be saved by reduced use.

3.4 Energy Impacts of Agricultural Conversions

The agricultural or secondary system conversion of water to municipal and industrial uses assumes that currently untreated water will be treated to a culinary standard, distributed, provided to end-users and re-treated. JVWCD currently treats about 75% of its total supply and conveys 25% to agricultural customers – about 30,000 ac-ft. As this volume of untreated water is converted incrementally to its new use, it is multiplied by the energy factors from the "Water Treatment" and "Distribution" segments of the water cycle. Additional wastewater effluent is multiplied by the user's estimated depletion factor. The resulting volume of water is multiplied by the system's wastewater energy factor to arrive at an added energy cost. Figure 11 shows the results within the estimation model for the JVWCD wholesale district, when all currently untreated water is converted to municipal and industrial uses. The results portrayed in the figure show that there is a corresponding increase in energy required with conversion,

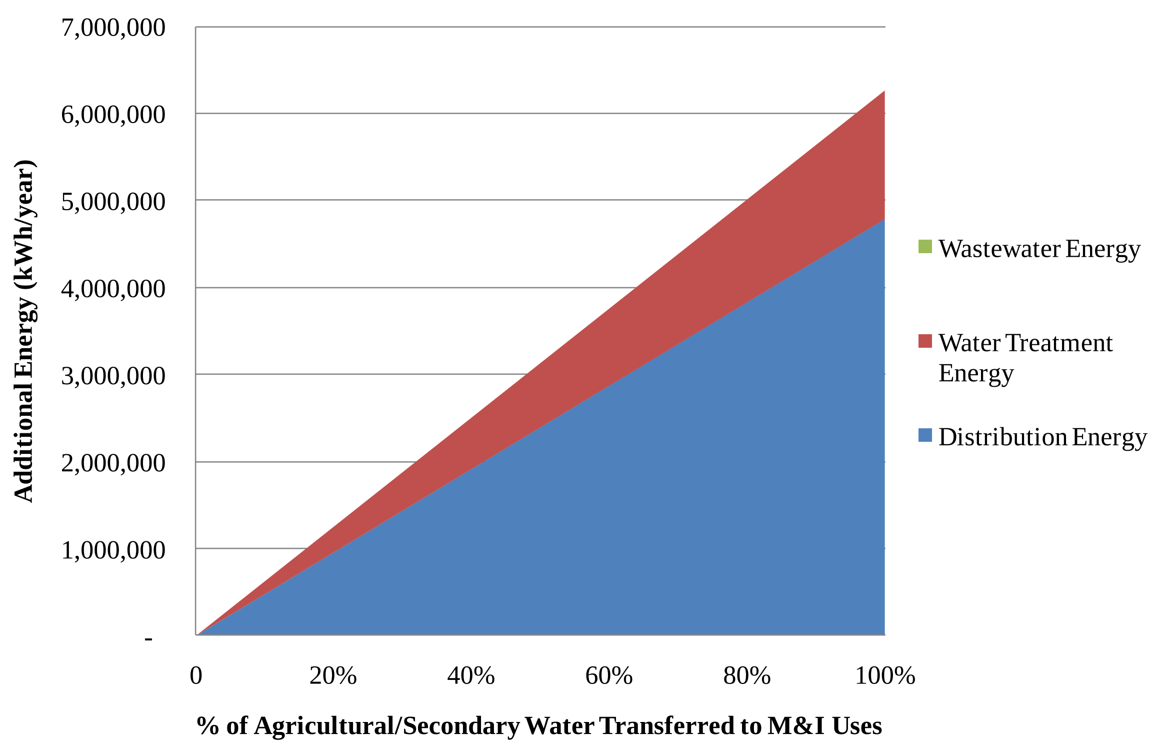

Figure 11. Increase in energy requirement for JVWCD wholesale district with conversion of agricultural/secondary water to municipal and industrial uses.

totaling approximately 6.3 million kWh each year, when 100% of available untreated water is converted. Most of the energy required for the transfer is due to increases of water volume in the "Distribution" water cycle phase. However, one of the primary assumptions of the model is that conventional water treatment is sufficient to bring available agricultural or untreated water to culinary standard. Upon review with JVWCD's management, a clarification was made concerning the water quality of agricultural water in the Salt Lake Valley. Water taken from some sources is indeed of a high enough quality to receive only conventional treatment, but any waters taken from Utah Lake has a much higher dissolved solids content and possibly algae. JVWCD managers clarified that to convert agricultural water to culinary uses for this particular location, additional energy-intensive reverse osmosis treatment would be required (Forsyth 2010).

3.5 Energy Impacts of Reduced Surface Water Availability

The final scenario modeled by the energy estimation tool is that of the impact of reduced surface water availability, as may occur during periods of drought, sedimentation of surface storage reservoirs and climate change. The assumption made by the model is that any reduction in available surface supply from that reported by the user in the model would be compensated for with an increase in groundwater withdrawals. However, the amount of groundwater increase is not linear with regard to such reductions for the JVWCD system. This is apparent when historic surface water and groundwater withdrawals are compared. There is significant variation in groundwater withdrawal with above or below average surface water availability – so much so that other contributing variables were investigated to help define their relationship to groundwater withdrawal. Correlation, linear regression and an analysis of variance (ANOVA) for statistical significance were performed on groundwater withdrawal data with regard to surface water supply, annual precipitation, and annual net evapotranspiration (ET_{net}), spanning 2001 – 2008. No single variable was found to exhibit a high degree of correlation or statistical significance, but the results suggested that ET_{net} and surface water availability combined may be strong predictors for groundwater withdrawal. To further evaluate this relationship, the historic surface water supply and groundwater withdrawals were normalized by annual ET_{net} for each year, and the resulting dataset analyzed for correlation and statistical significance. This relationship, normalized by ET_{net}, was found to exhibit a strong positive correlation with an R-squared value of 0.7478. The ANOVA also found this relationship to be statistically significant, with a P-value (the probability that the null hypothesis is true) of 0.0014. The equation of the linear regression line was then used to formulate the relationship used in the scenario module between surface water reductions, ET_{net}, and the resulting groundwater withdrawals. Tables of the statistical analysis of surface water supply, ET_{net} and groundwater variables are included in the Appendix.

Within the energy estimation model, after the user has specified a surface water source and groundwater source volume (if any), a graphic representation for low and high range water systems is displayed. Figure 12 is a graph of the resulting estimated increase in energy requirement from the additional compensatory groundwater pumping for JVWCD, the wholesale district. The figure shows an estimated increase in energy for both the low and high range with incremental reductions in available surface water. A

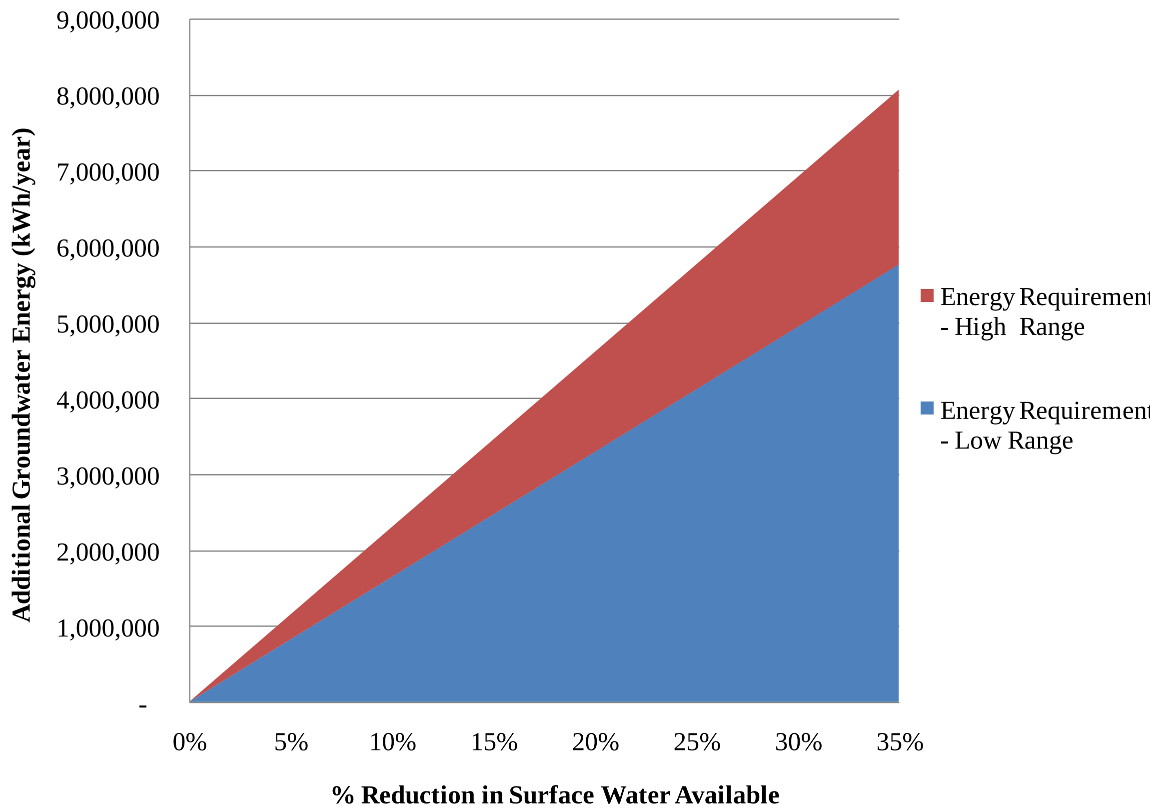

Figure 12. Additional energy requirement for JVWCD the wholesale district with decreasing surface water availability.

20% reduction in surface water is estimated to result in a 3.3 million kWh per year increase in energy consumption, whilst 35% amounts to approximately 5.8 million additional kilowatt hours per year for the low range system.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

The water devoted to energy production and the energy used for water-related services are directly linked. There are many emerging concerns about how much energy will be required to provide water to growing populations, especially in arid climates and regions of water shortage. Much research is ongoing that addresses these issues on a broad jurisdictional (national and statewide) scale, the results of which may be too generalized for the needs of individual water systems and local planners. Conversely, there are many studies that detail individual components of a water system that contribute to its overall energy requirement – especially in the realm of life cycle assessment (LCA). To fill the gap between these two research efforts, a midlevel, systemwide methodology for quickly estimating energy requirement and its response to alternate water supply and demand scenarios was developed. The methodology employed found that energy requirement could be estimated more accurately by disaggregating the water supply and consumption cycle into subgroups, based on key characteristics of the system. For each subcategory, an energy cost per unit volume of water, called an energy factor, was calculated using case study utility data. The energy factors derived from case study utility data were comparable to those found in prior research efforts, when differences in climate and geography were accounted for.

Using the energy factors as a framework for analysis, the developed model estimated the energy saved or additional energy consumed when alternate water supply and demand scenarios were envisioned. The first scenario modeled was that of a reduction in demand. The model estimated how much energy would be saved within each phase of the water cycle when such reductions take place – 8.9 million kWh or a 28% reduction of current energy usage. The second scenario modeled that of an agricultural/secondary water system conversion to municipal and industrial uses. It estimated how much additional energy would be required to incorporate this new source of water into the public water system. This was estimated to be 6.3 million kWh and a 20% increase of current energy requirement. The third scenario modeled the additional energy required to compensate for reduced surface water availability with compensatory increases in groundwater withdrawals. The model estimated that with a reduction of 35% in available surface water supply, an 18% increase in energy was necessary. When applied to JVWCD, its member agencies and three geographically dispersed water systems initially lacking extant energy data, the model estimated their energy requirements with a cumulative margin of error of 19.7%. With further refinement of energy factors and the addition of some additional model parameters, it is likely that modeling error will be reduced significantly.

Once the model is adjusted, it can be used by water planners and water system managers in many ways. First and foremost it can simply increase energy awareness among water agency decision-makers. Most of the agencies approached for this study had not considered what their energy requirement might be. Many were surprised by how much energy they used to operate their facilities when their data were entered into the model, or when they received their utility data. In this fashion the model can be used as a year-to-year assessment tool when actual utility data are entered, to verify that the system is functioning optimally (or at least nominally). A spike or dip in energy usage by a given category or facility could indicate a system error or a decrease in energy efficiency, which would in turn reveal components in need of additional maintenance. If similar water systems are using the model to summarize their baseline energy, the results can be compared to discover what treatment technologies are most energy efficient or which pumping schedule or setting is optimal for that type of system or region.

The model can also be used as a policy planning tool. For example, if energy efficiency is of concern for a municipality, it may be more effective to fund water efficiency programs to achieve energy efficiency goals depending on how much energy is used for water-related services. The integration of the two efficiency programs may be able to achieve gains that the individual programs cannot. Using the model to discover how much energy is devoted to water-related services and how much energy can be saved through demand reduction would help allocate funding dollars to one program or another. It can be used to identify strategic breakpoints in energy savings, such as the 10% reduction in demand eliminating the need to use the most marginal source of water for the case study.

The model can be used as a general planning tool. It can assess future energy needed with additional facilities or water development for growing populations or with demand reductions. It can assess energy required to treat water as it is converted to new uses. New capital improvement projects, such as a new storage reservoir, groundwater pumping facilities or a treatment plant, can be entered into a water system's baseline energy estimate to find the energy cost of such additions. The model can be used as an adaptive management tool. Alterations in the availability of surface water or groundwater in the future may have significant impacts on hydropower energy generation, the financial well-being of water agencies and extended or indirect climate impacts. It can help managers plan for these kinds of changes and adjust the operation of their systems to maximize efficiency and minimize externalities. And finally, the model can help water planners on a large-scale. For example, extrapolating the JVWCD energy factors to a statewide scale, similar to the study conducted by the California Energy Commission in 2005, reveals that Utah's water-related energy usage is much lower than California's estimate of 19.2%. When using the most recent estimates from the U.S. Geological Survey to estimate surface water withdrawals, groundwater withdrawals and public water supply, Utah uses approximately 4.3%–6.4% of its total energy budget on providing water to its citizens, as presented in Table 5. To further refine the percentage, the model could be sent to water agencies within a given state. Managers and operators would enter model inputs to the best of their knowledge and then return it to a central state agency for compilation. This would be an alternative method to discovering what portion of a state's energy budget is devoted to water-related services "outside the retail meter."

Each scenario posed by the study results in either a decrease or increase in energy necessary for the case study water system to function nominally. Depending on the size and sophistication of the system modeled, these impacts could range from a few thousand to millions of kilowatt hours.

Table 5. Water-related service energy usage in Utah

	MGD	Ac-ft/yr	Energy Factor (kWh/ac-ft)	Energy (kWh/yr)	Energy (GWh/year)
Source & Conveyance					
Surface Water/Springs[1]	4,160	4,659,200	100	465,920,000	466
Groundwater[1]	955	1,069,600	950	1,016,120,000	1,016
Recycled Water[2]	8	8,512	10	85,120	0
Water Treatment[3]	607	679,840	50	33,992,000	34
Water Distributed[4]	4,348	4,869,480	220	1,071,285,600	1,071
End-Use[5]				7,420,921,872	7,421
Wastewater Treatment[6]	486	543,872	850	462,291,200	462
Total Water-Related Energy Use in Utah				10,470,615,792	10,471

	Million BTU	Energy (kWh)	GWh
Total Energy Consumption in Utah[7,8]	826,500,000	242,247,150,000	242,247
Total Energy Consumption, excluding transportation[9]	561,000,000	164,429,100,000	164,429

% of Utah Energy Budget devoted to Water-Related Services	**4.3%**
% of Utah Energy Budget devoted to Water-Related Services, exluding transportation	**6.4%**

[1] Source: U.S. Geological Survey (2009). "Estimated Use of Water in the United States in 2005: Table 1. Total water withdrawals by source and State, 2005."
[2] Source: Utah Division of Water Resources (2005c). "Water Reuse in Utah."
[3] Source: U.S. Geological Survey (2009). "Estimated Use of Water in the United States in 2005: Table 2. Public-supply water withdrawals, 2005."
[4] Estimate of the percentage of total withdrawals that enter a distribution system - 85%.
[5] Source: CEC 2005 Water-Energy Report. Estimate 73% of water service energy-use is "Within the Retail Meter".
[6] Estimated indoor depletion of treated water/public water supply of 20%.
[7] Source: Utah Geological Survey (2009). "Energy Consumption and Expenditures in Utah, 1960 - 2008."
[8] 1 Million BTU = 293.1 kWh
[9] Source: Utah Geological Survey (2009). "Energy Consumption in Utah by End Use (Trillion Btu), 1960 - 2008."

Collectively, the alternate water supply and demand scenarios modeled have far-reaching financial and environmental repercussions. The increase in energy required to convey, treat and re-treat water posed by the latter two scenarios for the case study would result in greater utility cost (approximately $600,000 at an estimated industrial rate of $0.05 per kilowatt hour), additional water infrastructure and capital improvement projects. The financial impacts on water agencies of increases or decreases of energy usage can be estimated using current energy rates, but – with the possibility of carbon taxation, limitation and an increased emphasis on environmental concerns – it is likely to become unpredictably more expensive in the future.

From an environmental perspective, the case study system relies on utilities that derive their energy primarily from coal-fired thermoelectric power plants. Increases in energy usage would have a commensurate increase in GHG emissions and other harmful particulates into the atmosphere, which may in turn exacerbate surface water availability. Major increases in energy requirements would likely necessitate the installation of new power generating facilities. Also, the long-term environmental impacts of increases in groundwater withdrawals to compensate for reduced surface water availability are as yet unknown. Groundwater mining is already occurring periodically within the Salt Lake Valley – the amount withdrawn sometimes exceeds recharge. Other regions near the case study system that rely heavily on groundwater withdrawals, are experiencing stress to the point of land subsidence (Utah Division of Water Resources 2005b). The above serves to emphasize the importance of incorporating energy-related data into the decision-making process while reviewing existing or new water development options.

Items for future research include a further refinement and disaggregation of water cycle phases and investigation of methods for incorporating the end-use phase. Regionalizing the energy factors according to climate, geographic characteristics and/or groundwater surface elevations would improve the predictive accuracy of the model. More data are needed concerning the energy requirement of individual water system components, and what characteristics of the components predict energy usage. This could be facilitated by formulating a process whereby water system managers can easily relay their system components and actual energy totals to a database maintained for such an effort. A GIS-based database that is continuously refined, and where the most accurate energy factors are made available to model users, would be optimal. Incorporation of the interrelated nature of water agency water sales would also allow for better prediction of the regional impacts of the scenarios included in the model. It would enable the inclusion of upstream energy producers that take advantage of hydropower or energy efficient, gravity-fed systems.

Currently, one module of the model results is based on a relationship that incorporates ET_{net} as a predictive variable. This limits the model's use to areas that are similar in climate or at least experience similar ET_{net} values from year to year. This makes the model less accurate for areas that have very different climate patterns. Historic relationships between surface water and groundwater use, and how they relate to local variables, should be established before modeling dissimilar locations. Caution should be used when modeling any water system, as the model uses JVWCD as a framework for its assumptions. These may or may not yield valid results for very dissimilar systems.

Another assumption of the model, when run with the alternate water supply and demand scenarios, is that groundwater supply is available for pumping and within safe yields of the aquifer. Incorporating availability and overall groundwater health into the model would provide an increasingly complex analysis tool, as it would most certainly play an important role for decision-makers with some of the scenarios posed in the study. Incorporation of these modifications would increase understanding of how much energy plays a vital role in water supply, both now and for growing populations.

APPENDIX

METHODS AND RESULTS INFORMATION

Table 6. Energy factors for JVWCD and member agencies

	N	Average	STDV	Low Range	High Range
JVWCD					
WATER - SURFACE WATER	235	55.7	45.1	10.6	100.8
WATER - GROUNDWATER	205	968.1	413.9	554.2	1,382.0
WATER - TREATED	25	42.3	2.4	40.0	44.7
WATER - DISTRIBUTED	185	113.1	8.9	104.2	122.0
TOTAL	650				
Bluffdale City					
WATER - SURFACE WATER	-	-	-	-	-
WATER - GROUNDWATER	-	-	-	-	-
WATER - TREATED	-	-	-	-	-
WATER - DISTRIBUTED	-	-	-	-	-
TOTAL	-				
Draper City					
WATER - SURFACE WATER	-	-	-	-	-
WATER - GROUNDWATER	-	-	-	-	-
WATER - TREATED	-	-	-	-	-
WATER - DISTRIBUTED	35	483.9	56.8	427.1	540.7
TOTAL	35				
Granger-Hunter Improvement District					
WATER - SURFACE WATER	-	-	-	-	-
WATER - GROUNDWATER	45	955.5	109.6	846.0	1,065.1
WATER - TREATED	-	-	-	-	-
WATER - DISTRIBUTED	175	169.2	17.9	151.3	187.1
TOTAL	220				
Herriman City					
WATER - SURFACE WATER	-	-	-	-	-
WATER - GROUNDWATER	35	778.1	192.1	586.0	970.1
WATER - TREATED	5	4.9	4.9	0.1	9.8
WATER - DISTRIBUTED	45	46.1	89.3	(43.2)	135.4
TOTAL	85				
Kearns Water Improvement District					
WATER - SURFACE WATER	-	-	-	-	-
WATER - GROUNDWATER	60	1,261.8	90.6	1,171.3	1,352.4
WATER - TREATED	-	-	-	-	-
WATER - DISTRIBUTED	60	311.6	9.1	302.5	320.7
TOTAL	120				

Table 6. (cont.)

	N	Average	STDV	Low Range	High Range
Midvale City					
WATER - SURFACE WATER	-	-	-	-	-
WATER - GROUNDWATER	15	487.7	41.2	446.5	528.9
WATER - TREATED	-	-	-	-	-
WATER - DISTRIBUTED	15	91.6	46.5	45.1	138.2
TOTAL	30				
South Jordan City					
WATER - SURFACE WATER	-	-	-	-	-
WATER - GROUNDWATER	-	-	-	-	-
WATER - TREATED	-	-	-	-	-
WATER - DISTRIBUTED	85	14.0	2.7	11.2	16.7
TOTAL	85				
South Salt Lake Culinary Water					
WATER - SURFACE WATER	-	-	-	-	-
WATER - GROUNDWATER	-	347.7	118.5	229.2	466.2
WATER - TREATED	-	-	-	-	-
WATER - DISTRIBUTED	85	325.7	85.3	240.4	411.0
TOTAL	85				
Taylorsville Bennion Water Improvement District					
WATER - SURFACE WATER	-	-	-	-	-
WATER - GROUNDWATER	85	874.0	24.3	849.8	898.3
WATER - TREATED	-	-	-	-	-
WATER - DISTRIBUTED	35	130.9	8.8	122.2	139.7
TOTAL	120				
West Jordan City					
WATER - SURFACE WATER	-	-	-	-	-
WATER - GROUNDWATER	25	885.6	33.2	852.3	918.8
WATER - TREATED	-	-	-	-	-
WATER - DISTRIBUTED	120	157.3	37.0	120.3	194.3
TOTAL	145				
White City Water Improvement District					
WATER - SURFACE WATER	-	-	-	-	-
WATER - GROUNDWATER	25	798.5	124.1	674.4	922.7
WATER - TREATED	-	-	-	-	-
WATER - DISTRIBUTED	120	136.9	49.0	88.0	185.9
TOTAL	145				

Table 7. Energy factors for wastewater treatment facilities

WWTP	EF (kWh/ac-ft)
CVWRF	450
CVWRF Recycled Water	10
SVWRF	875

Wastewater Treatment	WWTP Used	WWTP EF (kWh/ac-ft)
Bluffdale City	SVWRF	875
Draper City	SVWRF	875
Granger-Hunter ID	CVWRF	450
Herriman City	CVWRF	450
Kearns WID	CVWRF	450
Midvale City	SVWRF	875
South Jordan	SVWRF	875
South Salt Lake CW	CVWRF	450
Taylorsville-Bennion WID	CVWRF	450
West Jordan	SVWRF	875
White City WID	CVWRF	450
	MEAN	643.2
	STDV	221.9

Table 8. Composite energy factors for all water agencies

ALL AGENCIES	n =	Average	STDV	Low Range	High Range
WATER - SURFACE WATER	235	55.7	45.1	-	100
WATER - GROUNDWATER	495	817.5	127.5	700	950
WATER - RECYCLED	1	10.0	-	-	-
WATER - TREATED	30	42.3	2.4	40	50
WATER - DISTRIBUTED	960	180.0	37.4	140	220
WASTEWATER TREATMENT	2	643.2	221.9	400	850

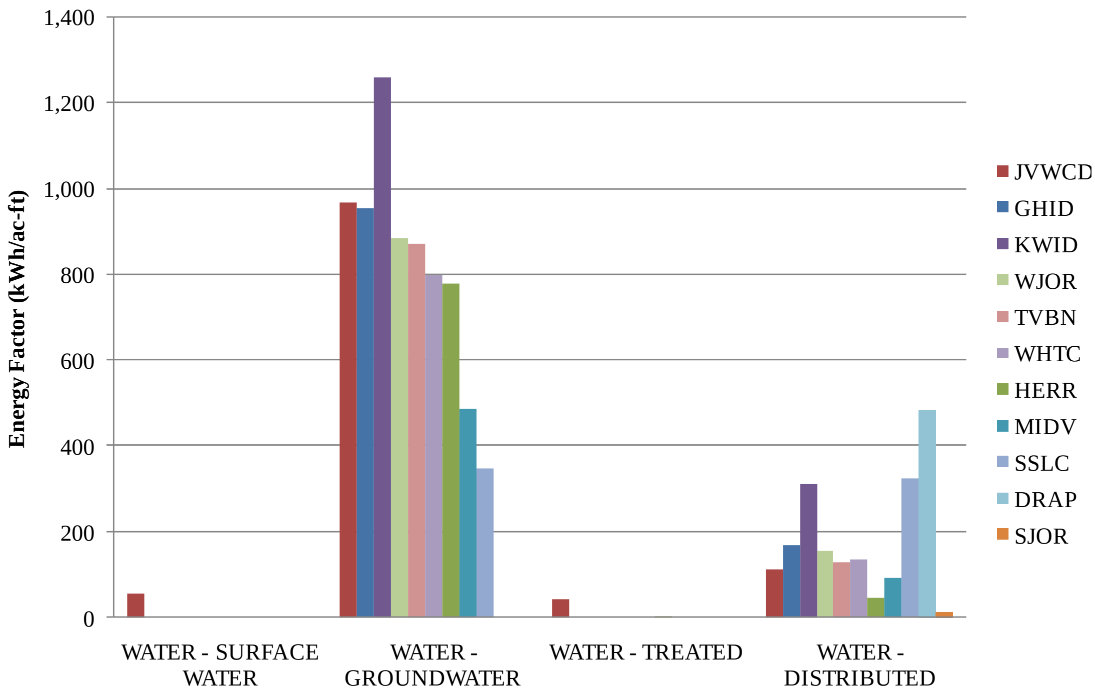

Figure 13. Graphic display of energy factors for JVWCD and member agencies

Table 9. Statistical analysis results of surface water, ET_{net} and groundwater withdrawals

Year	Surface Water Supply (ac-ft)	Groundwater Withdrawals (ac-ft)	Etnet (in.)	Surface Water Norm. (ac-ft/in)	Groundwater Norm. (ac-ft/in)
2001	97,359	21,217	28.24	3,448	751
2002	89,162	20,002	27.47	3,246	728
2003	93,357	14,540	25.97	3,595	560
2004	85,879	14,139	24.18	3,552	585
2005	102,446	6,989	23.63	4,335	296
2006	107,956	7,816	24.31	4,441	322
2007	106,777	9,186	28.28	3,776	325
2008	102,129	8,773	26.07	3,917	337

General Statistics		
Mean	3,789	488
Variance	177972.534	36536.991
Skew	0.565	0.381
Stdev	421.868	191.147
Low	3,367	297
High	4,211	679

Correlation Statistics				
Correlation R-value				-0.864730006
Pearson				-0.864730006
Significance (α) = 0.05	0.1	0.05	0.02	0.01
Degrees of Freedom = 6	0.622	0.707	0.789	0.834
**Summary: 0.865 > 0.707*				

Table 9. (cont.)

Regression Statistics	
Multiple R	0.864730006
R Square	0.747757984
Adjusted R Square	0.705717648
Standard Error	103.692775
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	191246	191245.7858	17.7866795	0.005577121
Residual	6	64513	10752.19159		
Total	7	255759			

** Correlation is statistically significant*

	Coefficients	*SE*	*t Stat*	*P-value*
Intercept	1972.24788	353.88	5.573278398	0.001415302
Surface Water - (ac-ft/in)	-0.39180541	0.0929	-4.217425696	0.005577121

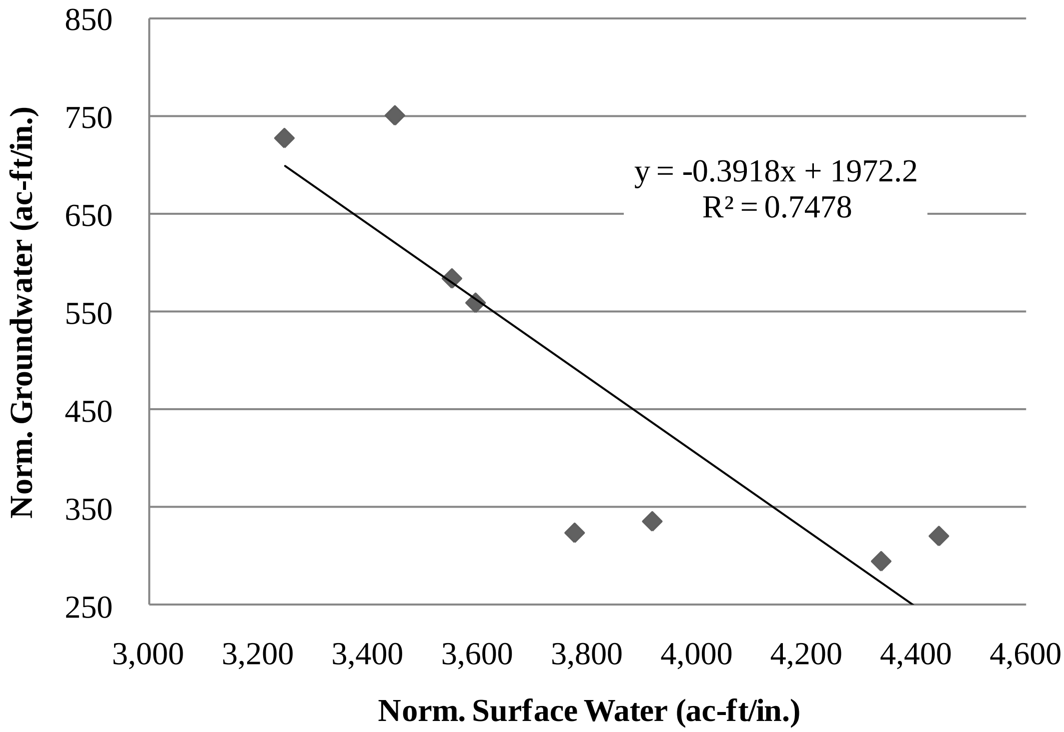

Figure 14. Normalized groundwater withdrawals vs. surface water supply

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